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Evaluation of Methods for Measuring and Controlling Hydrocarbon Emissions from Petroleum Storage Tanks

Battelle Columbus Labs, Ohio

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EVALUATION OF METHODS FOR MEASURING AND CONTROLLING HYDROCARBON EMISSIONS FROM PETROLEUM STORAGE TANKS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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EPA COMMENT

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A major objective of this study, initiated by EPA with Battelle in March 1976, was to develop testing procedures to conduct short-term hydrocarbon emissions tests on floating roof storage tanks either by modifying existing test methods or developing new ones.

The most promising procedure appeared to be the use of a local enclosure over the entire seal space wherein hydrocarbon emissions would be calculated from the inlet and outlet hydrocarbon concentration in an air stream of measured volume flowing into and out of the enclosure. This technique was based in part on a theoretical study[1] by Chicago Bridge and Iron Company (CBI) which hypothesized that the principal mechanisms causing loss were; (1) air solution and dissolution caused by diurnal product temperature change, and (2) barometric pressure change.

Data subsequently collected by CBI during August-November 1976 in an experimental test program[2] indicates that wind flow over a tank may be the dominant factor causing emissions through tank seals rather than the mechanisms stated above. The loss mechanisms caused by wind flow over a tank may not necessarily be the same as those caused by continuous steady-state air flow directly over an enclosed seal. Users of the enclosure method should give consideration to the fact that no experimental data exist that substantiate emissions are the same in either case.

References

1. Chicago Bridge and Iron Company, SOHIO/CBI Floating Roof Emission Test Program, Preliminary Information, August 27, 1976.

2. Chicago Bridge and Iron Company, SOHIO/CBI Floating Roof Emission Test Program, Final Report, November 18, 1976.

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November 1976

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LIST OF SYMBOLS

A	Frequency factor
C	Compressibility factor
C_a	Adjustment factor for small tanks
D	Tank diameter (feet in empirical equation)
F	Working loss (barrels in empirical equation)
F_p	Paint factor
ΔG	Volume of liquid lost from breathing
H	Average outage (feet in empirical equation)
K_T	Turnover factor
K_f	Tank type factor
K	Factor depending on fuel
k_s	Recommended seal factor
k_c	Recommended fuel factor
k_p	Recommended paint factor
L_z	Standing storage loss of floating roof tank (barrels per year)
L_y	Breathing loss of fixed roof tank (barrels per year)
M	Molecular weight
m	Mass
N	Turnover per year
n	Exponent
p	Vapor pressure
p_1	Vapor pressure at minimum liquid surface temperature
p_2	Vapor pressure at maximum liquid surface temperature
P_a	Ambient pressure
P_1	Gage pressure at which tank vacuum vent opens
P_2	Gage pressure at which tank pressure vent opens
ΔP_w	Weekly amplitude of barometric pressure
Q	Volume of liquid pumped into tank (barrels in empirical equation)
R	Universal gas constant
s	Standard deviation
T_1	Absolute minimum average vapor space temperature

T_2	Absolute maximum average vapor space temperature
ΔT	Ambient temperature change (^{o}F in empirical equation)
V_1	Minimum volume of vapor space
V_2	Maximum volume of vapor space
ΔV	Volume of vapor loss by breathing
V_t	Tank volume
V_w	Average wind velocity (miles per hour in empirical equation)
ρ_L	Density of liquid
V	General enclosed volume above seal in enclosure methods
V_P	Volume contained under a portable roof
V_L	Volume contained under a local enclosure
L	Distance from floating roof to top of tank
b	Distance from tank wall to point of local enclosure on floating roof
h	Distance from floating roof to point of local enclosure on tank wall
$\dot{c}$	Rate of hydrocarbon concentration buildup
$\dot{Q}_{HC}$	Assumed hydrocarbon emission rate
Re	Reynolds number
ρ	Density of gas in enclosed volume above seal
d_H	Hydraulic diameter
$\dot{Q}_L$	Minimum volume flow in enclosed space above seal for turbulent flow
t_V	Volume turnover time for enclosed space above seal
λ_{ON}	Wavelength of laser light in absorption range for desired species
λ_{OFF}	Wavelength outside of absorption range of desired species
I_{ON}	Intensity of laser beam in absorption range
I_{OFF}	Intensity of laser beam outside of absorption range
U	Velocity of gas flow through enclosed space above seal
α	Ratio of change in fluid surface temperature to corresponding change in ambient temperature
β	Ratio of change in vapor temperature to corresponding change in ambient temperature
θ	Activation energy

SUMMARY

The current methods used by EPA to estimate hydrocarbon emissions from petroleum storage tanks have recently come under criticism by various segments of the petroleum industry. The EPA emissions estimation methods are based on API correlations which were developed around emissions data obtained in the late 1930's and early 1940's. This data base was limited in coverage and has been claimed to be antiquated or not representative of current technology, but collecting new data using approved API test procedures would require many months to possibly several years.

The purpose of this study was to determine advances made in tank design towards controlling hydrocarbon emissions, evaluate the validity of the API correlations and test procedures when applied to modern tanks, and develop new test procedures or modify existing procedures to conduct short-term emissions tests on modern petroleum storage tanks.

The results of the study showed that the floating roof was the most common means of controlling emissions from storage tanks and that most advances in design were directed at increased safety, durability, and lower cost. No actual experimental data were found to indicate that any particular tank emission control system was better at controlling emissions than any other. It was also found that the existing API data base and correlations are of questionable accuracy, especially when applied to stocks with true vapor pressure less than 2.0 psia or tanks with diameters greater than 150 feet. The API emissions test procedures were found to be technically sound although they require extensive test times to obtain significant results. Little chance was seen to increase accuracy or reduce the test time of these procedures. Several new test

procedures were analyzed and one was felt to have promise of achieving accurate emissions results in substantially reduced test times. It was estimated that emission tests could be performed in a few hours, although the actual time a tank would be out of service for testing would be on the order of several weeks or longer to allow for equipment setup.

INTRODUCTION

On the basis of present predictive methods, hydrocarbons emitted from petroleum storage tanks appear to contribute significantly to the oxidant burden in many Air Quality Control Regions. The procedures currently used by EPA in estimating these emissions are based on correlations developed by the American Petroleum Institute which were compiled using emissions data taken in the late 1930's and early 1940's.

The correlations, which are primarily based on a symposium on evaporation loss held in 1952[1], are described in detail in API Bulletins 2517[2], 2518[3], and 2519[4]. They cover emissions from fixed roof storage tanks and storage tanks with various types of floating covers.

The data base for all these correlations consists of a compilation of tests on individual tanks compiled by various petroleum companies. These tests reportedly were conducted following the general test procedures described in API Bulletin 2512[5]. However, because all the tests were run prior to publishing of API 2512 (July, 1957) strict adherence to these procedures cannot in all cases be guaranteed.

Various segments of the petroleum industry have charged that the correlations are inaccurate and do not account for improvements in storage tank design that have been made since the basic data base was developed. Also, the data base was insufficient in dealing with liquids with low true vapor pressures and large tanks over 150 feet in diameter. In addition, the test methods used to develop the data base for the correlations are time consuming (requiring many months to sometimes several years) and may not have sufficient accuracy to measure emissions at the low levels now claimed by tank operators and vendors.

Two segments of the petroleum industry - one represented by the consortium of Chicago Bridge and Iron (CBI) and Standard Oil of Ohio (SOHIO), and the other by the Western Oil and Gas Association (WOGA) - have been conducting their own programs to better define the characteristics and magnitudes of hydrocarbon emissions from petroleum storage tanks.

The CBI/SOHIO program involves tests on tanks 20 feet and 8 feet in diameter which were specially constructed to allow evaluation of specific variables (such as temperature, windage, and degree of air stabilization) on hydrocarbon emissions. The WOGA program involves field emission tests on a number of floating and fixed roof storage tanks in the Los Angeles basin area using the density change test method (with a thin layer of hydrocarbon over water to speed results) essentially as described in API Bulletin 2512[5] for floating roof tanks and the vapor metering method as described in API 2512 for fixed roof tanks.

These programs represent ambitious undertakings and the results of each will undoubtedly contribute useful knowledge to the overall understanding of hydrocarbon emissions from storage tanks. EPA is following the conduct and results of each program closely and is exchanging information with both sponsoring organizations.

However, the lack of applicable test data and basic understanding of hydrocarbon emissions from petroleum storage tanks coupled with the high intensity of interest on the part of the industry and government organizations have pointed up the need for this study. The purpose of this report is to serve as a survey of the state of the art of petroleum storage tank design, an analysis of the accuracy and applicability of the existing API emissions correlations and test procedures when applied to modern storage tanks, and an evaluation of the potential for developing a short-term field test procedure which would allow accurate measurement of hydrocarbon emissions.

OBJECTIVES

The objectives of this study were three-fold:

(1) Conduct a survey to define the state of the art of petroleum storage tank design relative to controlling emissions of hydrocarbons.

(2) Evaluate the validity of the API correlations used by EPA in estimating hydrocarbon emissions from fixed roof tanks and tanks with floating roofs. Determine whether these procedures can be extrapolated to stocks with true vapor pressures less than 2.0 psia and to tanks with diameters greater than 150 feet in diameter. Also, evaluate the API test procedures used in developing the data base for the correlations and determine whether they might be modified to conduct future short-term tests on modern tanks.

(3) Develop short-term test procedures for accurately measuring hydrocarbon emissions from modern tanks with floating roof tanks.

TECHNIQUES USED FOR CONTROLLING HYDROCARBON EMISSIONS FROM PETROLEUM STORAGE TANKS

Loss of hydrocarbon vapors through evaporation from petroleum storage tanks has been of interest to the petroleum industry for many years. Because these lost hydrocarbons represent a salable product the industry has employed various types of control devices to minimize this loss. Coincidentally these devices also reduce the amount of unwanted hydrocarbon emissions to the atmosphere providing a double benefit to both the petroleum industry and the environment.

Devices for limiting losses of hydrocarbons from petroleum storage tanks can generally be classed into three groups: (1) those that are designed to prevent vapor formation (such as floating roofs and plastic foams) by limiting the amount of hydrocarbon liquid surface area exposed to the atmosphere thus preventing evaporation, (2) variable vapor space devices to allow for vapor expansion and contraction with flexible roofs and diaphragms, and (3) vapor recovery systems that are designed to collect the hydrocarbon vapor such that it can be used as a fuel, incinerated, or condensed back into liquid form. Within each of the three groups a variety of types of systems are available depending on the vendor and the application.

Floating Roofs

The most common type of device found in group 1 consists of a roof or cover that floats on the surface of the hydrocarbon liquid in a cylindrical storage tank. These roofs are made to cover as much of the liquid surface area as possible while leaving sufficient space between the edge of the roof and the tank shell to allow them to move freely up and down within the tank without binding on the sides. This annular rim space is usually filled with a flexible seal arrangement that hugs the inside surface of the tank shell thus further limiting the amount of liquid surface area exposed to the atmosphere.

Floating roofs are by far the most common type of hydrocarbon loss control device used for petroleum storage tanks. It has been estimated by a large manufacturer that there are on the order of 10,000 floating roof storage tanks in use today. They can generally be classed as external -- where the floating roof acts as the tank roof serving as the only barrier between the stored liquid and the environment -- and, internal -- where a fixed roof covering the top of the tank shields the floating roof from the elements. As part of this project a variety of vendors of floating roof equipment and seals were contacted to determine specific features and variations in design. A list of the specific vendors contacted is included in Appendix A.

External Floating Roofs

External floating roofs are most common in areas where weather conditions are not severe such as the southwest and gulf coast regions of the country. Because they are continually exposed to the elements they are generally of heavier construction and more rugged than internal floating roofs. Designs are fairly standard and have not changed much over the years. Figure 1 shows the three basic configurations used--the pan, pontoon, and double deck types.

External floating roofs are made of a flat section of sheet steel welded or riveted together on the edges to form a continuous membrane-like cover. The pontoon and double deck types have leak proof flotation sections with numerous bulkheads to ensure against their sinking in the hydrocarbon liquid during upsets or periods of rapid filling. Rain water is usually drained from the center of the roof through a flexible drain pipe which extends under the roof through the hydrocarbon liquid and exits at the base of the tank.

The roof itself forms a vapor tight structure, however, there are various points around the roof where hydrocarbon leakage can occur. The major point of leakage is from the annular space between the roof and

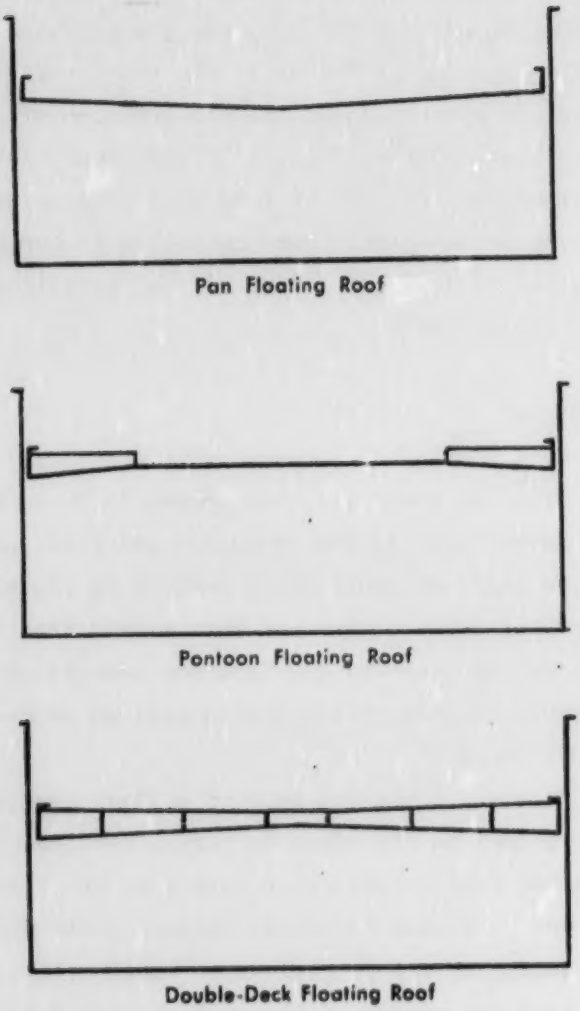


FIGURE 1. FLOATING ROOF TANK DESIGNS

tank shell. This space is usually about 1/2 to 1 foot in radial dimension and at all times must be great enough so that the roof does not bind on the tank walls as it travels up and down with the liquid level. This annular space is usually filled with a flexible seal which is designed to rub against the tank wall thus centering the roof and keeping the exposed surface area to a minimum. Figure 2 shows the annular rim space between the floating roof and shell of a large gasoline storage tank looking down from the top of the tank. Figure 3 shows a closeup of the seal with the weather guard (a metal shield to keep rain and sun off the seal) retracted. Seals are normally sold separately from the roof and do not necessarily depend on roof design. A more complete discussion of types of seals used is presented later in this section.

Other points of potential hydrocarbon leakage are access hatches, gage and sampling ports, anti-rotation columns, and roof supports. Figure 4 shows various roof support legs and a typical access hatch on a new floating roof tank not yet in service. The roof support legs project down through the roof and maintain the roof a certain distance off the base of the tank when the tank is not in service. These legs are adjustable with usually a high and low setting, the high setting allowing for maintenance crews to work under the roof when necessary, and a low setting which allows the tank to be nearly emptied without damaging inlet and outlet pipes or other equipment on the floor of the tank inside. The access hatch allows for entrance below the roof and is normally sealed with a vapor tight cover as shown in Figure 5. The roof support legs can also be sealed against vapor leakage in several ways such as a simple placement of plastic bags over each support as shown in Figure 6.

Figure 7 shows an anti-rotation column that also serves as a gaging port. This hollow pipe is fixed at the top and bottom of the tank and extends through a hole in the roof thus preventing rotation. Because of the sliding contact between the roof and column it cannot be positively sealed against vapor leaks. Sliding seals can and are being placed around the columns to limit vapor emissions such as was observed in field visits. However,

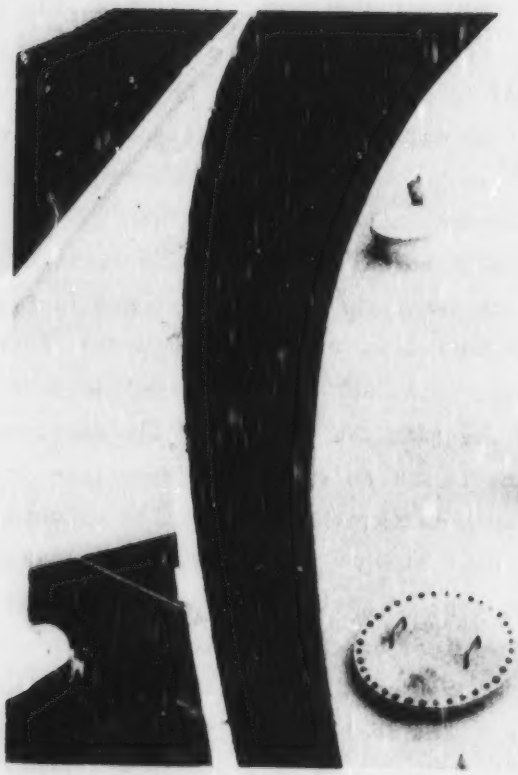


FIGURE 2. VIEW OF FLOATING ROOF FROM TOP OF TANK WALL SHOWING SEAL AREA

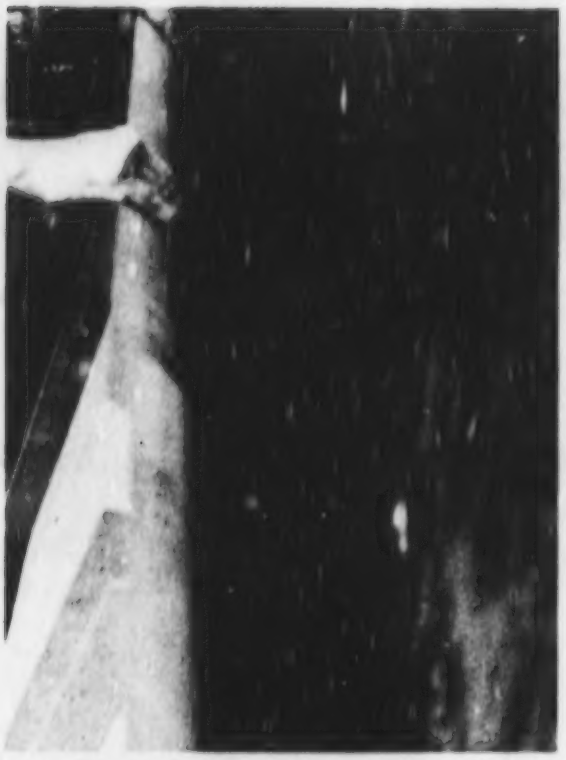


FIGURE 3. FABRIC FLOATING ROOF SEAL WITH WEATHER GUARD RETRACTED

FIGURE 4. TOP OF FLOATING ROOF SHOWING LEG SUPPORTS AND ACCESS HATCH

FIGURE 5. ACCESS HATCH SHOWING HATCH COVER REMOVED

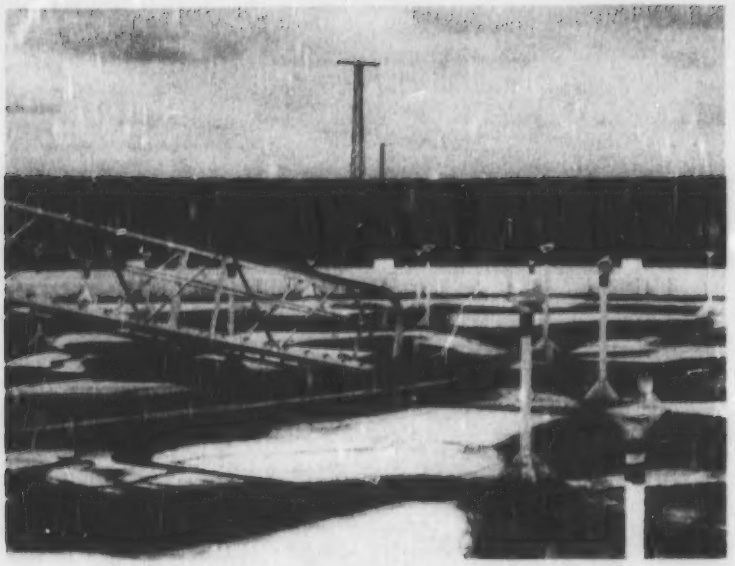


FIGURE 6. TOP OF FLOATING ROOF SHOWING BAGS OVER LEG SUPPORTS

FIGURE 7. TOP OF FLOATING ROOF SHOWING ANTI-ROTATION COLUMN AND SAMPLING PORTS

this point of emissions is considered small (due to the small amount of exposed liquid surface involved) compared to potential emissions coming through the annular rim space around roof seals.

Internal Floating Roofs

Internal floating roofs float on the surface of the hydrocarbon liquid inside a conventional fixed roof type tank. The fixed roof is vented to allow sufficient air to circulate inside the tank to maintain the hydrocarbon vapor above the floating roof at a concentration below the lower explosive limit (LEL). The method in which they prevent emissions of hydrocarbons to the atmosphere is analogous to that of external floating roofs. The major differences are those of methods and materials of construction.

Internal floating roofs need not be as rugged and sturdy as external floating roofs because they are not directly exposed to the elements and seldom have to support any weight except that of the roof itself. Also, all internal floating roof designs studied are such that they can be retrofitted to existing fixed roof tanks. In most designs all materials of construction can be passed through existing access hatches in the tank. This places unique restrictions on methods and materials of construction which have been overcome by the various vendors in a variety of inventive ways.

Figure 8 shows the three basic types of internal floating roof designed used. The designs found in Figures 8a through 8d are those actively promoted by most vendors today. The designs in Figures 8a and 8b use an aluminum skin laid up on a light weight aluminum framework all of which floats on a series of aluminum or polyurethane filled pontoons. The vapor space under the roof is usually sealed off from the annular rim space by a continuous metal skirt around the circumference of the roof extending 4 to 5 inches into the hydrocarbon liquid. Usually a flexible type wiper seal such as that shown in Figure 8 is used to close the space between the roof and tank wall.

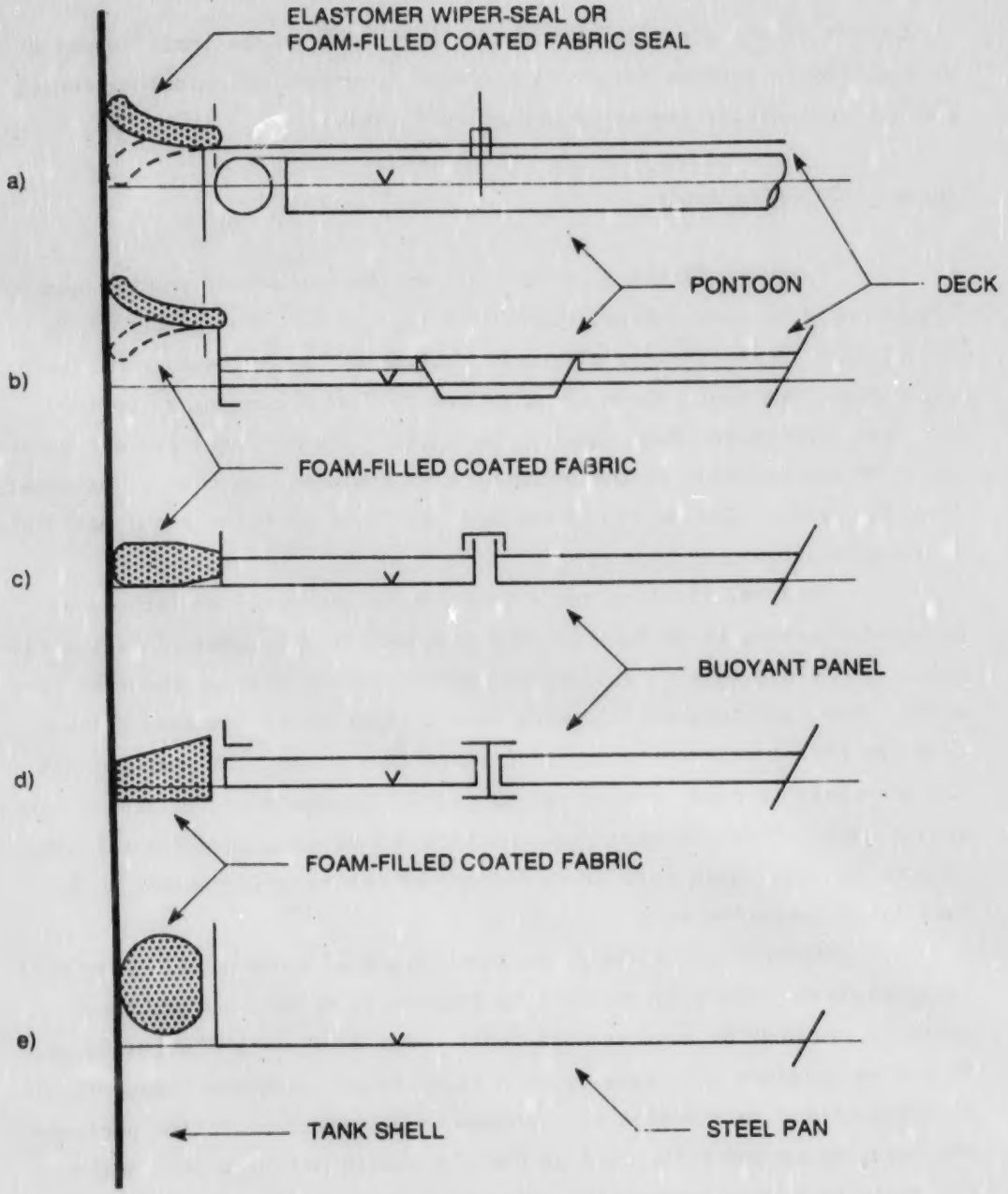


FIGURE 8. INTERNAL FLOATING ROOF CONFIGURATIONS
(Courtesy of the American Petroleum Institute)

Figures 8c and 8d show another common type design employing a flat bouyant roof that rests directly on the liquid surface. The roof can be made of sheet aluminum with a honeycomb core, fiberglass over polyurethane, or other combinations of metal and plastics. Usually a pillow seal such as that shown is employed.

The flat pan roof shown in Figure 8e has also been employed in the past as an internal floating cover. A variety of types of seals can also be used with this type roof.

Because of the similarity to external floating roofs, internal floating roofs tend to have the same points of emissions and the same problems limiting these emissions. For all the designs studied, the basic roof itself, if constructed and maintained properly, should be impervious to hydrocarbon vapors. Therefore, the principal points of emissions are the annular rim space between the roof and tank wall and places where the roof must seal around fixed vertical sections such as gaging wells, support columns for the fixed roof, anti-rotation columns or cables, and internal access ladders. Other potential emission points are access hatches and roof support legs or suspension cables for maintaining the roof a desired distance off the tank floor when the tank is emptied.

Various types of sliding seal arrangements have been devised for sealing the roof around the fixed vertical elements in the tank. Access hatches and roof support members can be positively sealed off in much the same manner as those on external floating roofs.

As was the case with external floating roofs the major potential point of emissions from internal floating roofs appears to be the seal area. Seals used vary considerably but are similar in many respects to those used on external floating roofs. Seals are discussed in more detail in the next section.

Floating Roof Seals

A great deal of interest has recently been focused on the design of seals used to fill in the gap between the floating roof and tank shell.

Basically, seals can be categorized into two groups (1) mechanical or shoe type seals and (2) flexible resilient fabric or tube type seals.

(1) Mechanical or shoe seals have been used since 1920. They consist of a rigid metal strip which is forced out against the tank shell usually by weights attached to a series of lever arms. Figure 9 shows a cross section view of a typical mechanical seal. A fabric section connects the top of the seal near the tank wall to the edge of the floating roof thus closing off the annular space to hydrocarbon vapors. These types of seals are durable and resist wear from constant sliding against the tank walls. However, because they are rigid they don't conform well to irregularities in the tank wall or to protrusions such as welds or rivet heads. In some cases helper springs have been used to provide additional force against the top of the seal to get more consistent contact with the tank wall. An example of such an application is shown in Figure 10. Another means of improving the sealing effectiveness of these seals is to install a secondary flexible seal above the primary mechanical seal. Two examples of such applications are shown in Figure 11. Figure 11a shows a tube type wiper seal consisting of a polyurethane core with a canvas covering. Figure 11b shows a Maloney type rubber seal that is shown partially installed.

(2) Flexible fabric type seals are a relatively recent innovation in seal design and are becoming more popular as increased emphasis has been placed on obtaining tight, consistent contact. Figure 12 shows two common examples of fabric seals installed on an external double deck floating roof. Figure 12a is a resilient foam seal which has a urethane foam core covered by a tough flexible synthetic material that is attached to the floating roof. Figure 12b has a liquid filled core which provides the sealing force against the tank wall.

Flexible fabric seals are used extensively on internal floating roofs in a variety of configurations. Figure 8 (see section on Internal Floating Roofs) shows three different examples as they might be employed on the three basic types of internal floating roofs. Figure 8a shows a

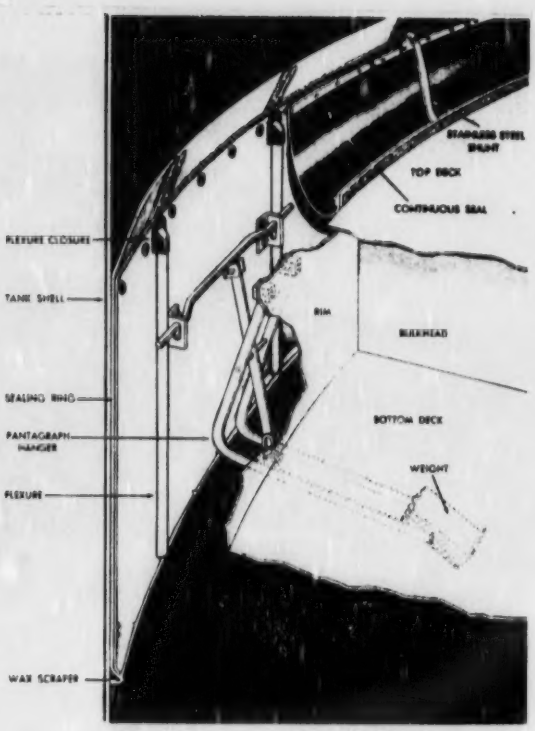
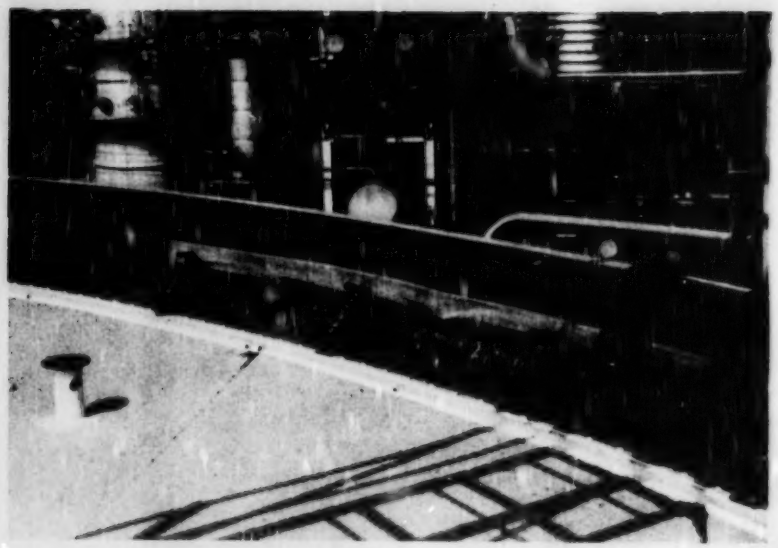


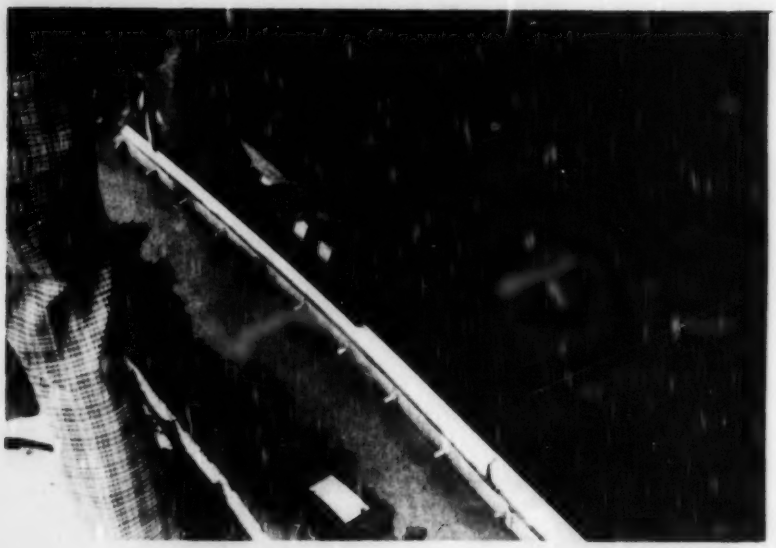
FIGURE 9. TYPICAL MECHANICAL SEAL

(Courtesy Chicago Bridge and Iron)

FIGURE 10. MECHANICAL SEAL WITH HELPER SPRINGS TO IMPROVE SEALING

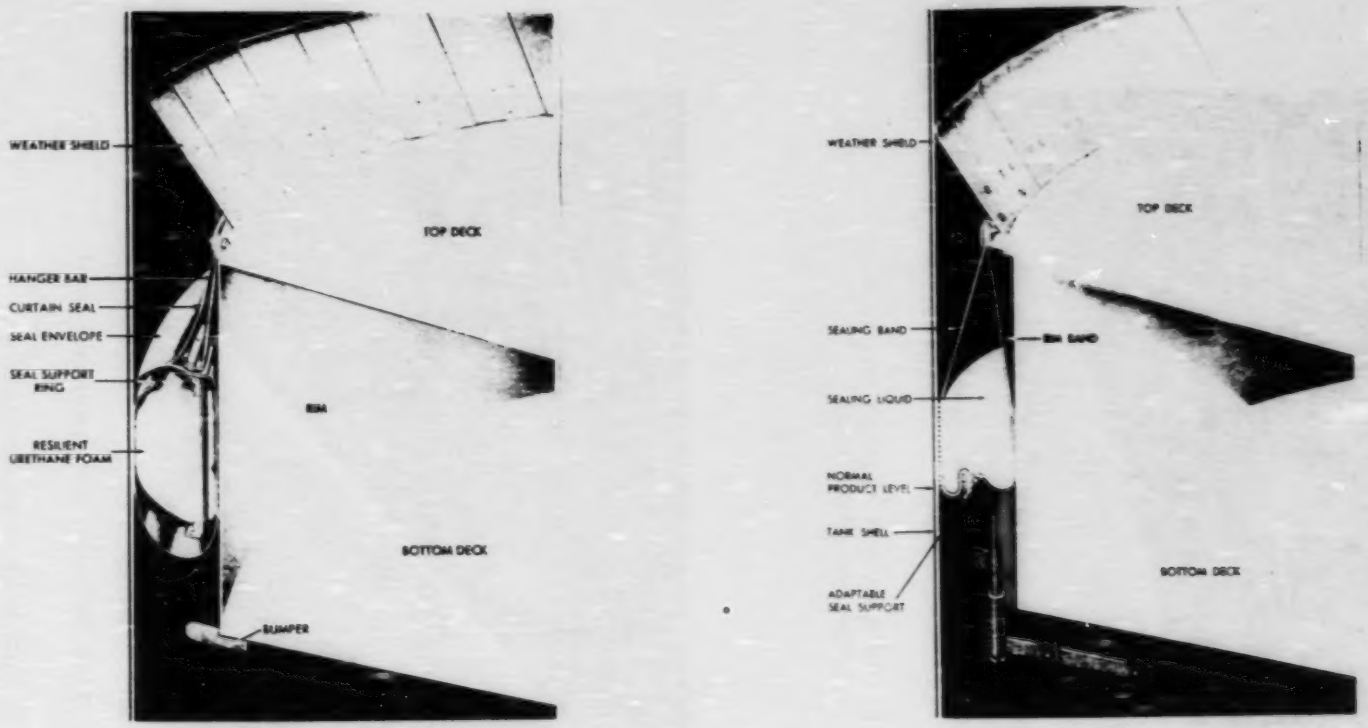


a. With helper springs and tube type secondary seal



b. With Maloney type secondary seal

FIGURE 11. MECHANICAL SEAL



a. Urethane foam

b. Liquid filled

FIGURE 12. FABRIC SEALS

(Courtesy Chicago Bridge and Iron)

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wiper type seal consisting of either an elastomer type material or foam filled coated fabric. These seals contact the wall above the liquid surface and flop back and forth as the roof goes up and down. Figures 8b and 8c show urethane foam filled seals with coated fabric covers which ride with the roof either at the liquid level or just above it as shown.

The flexibility of fabric seals allows them to conform more readily to irregularities in the tank wall thus providing a tighter more consistent fit than mechanical seals. In areas of severe weather they are usually protected by weather guards (see Figure 3), or by fixed roofs over internal floating roofs. In some cases metal wear plates have been installed to increase life as shown in Figure 13. However, rigid wear plates have many of the same disadvantages of mechanical seals in that they are inflexible and also some gaps will occur around the edges.

Comments on Advances in Floating Roof Design

The design and construction of floating roofs for reducing hydrocarbon losses from petroleum storage tanks has evolved over the years in a very competitive market place. As such, many innovations and unique features have been incorporated into the various vendor's designs to provide them with an edge over the competition. However, the floating roof is generally considered inherently effective in reducing hydrocarbon losses and most vendors claim reductions of around 95 percent over fixed roof tanks. Such a reduction is also predicted by comparing calculations made in API Bulletin 928[6] based on the API correlations of Bulletins 2517 and 2518[2,3]. Therefore, most all design improvements over the years have been directed at reduced time and cost of construction and maintenance, greater safety and reliability--especially in trying to eliminate the possibility of sinking--and in improving the life and durability of the structure. The same is also true of seals in that most design features concentrate on durability, ability to conform to the tank wall, and cost. No specific experimental data were found in contacts with vendors showing that any particular floating roof or seal arrangement is superior to others in terms of controlling hydrocarbon emissions.

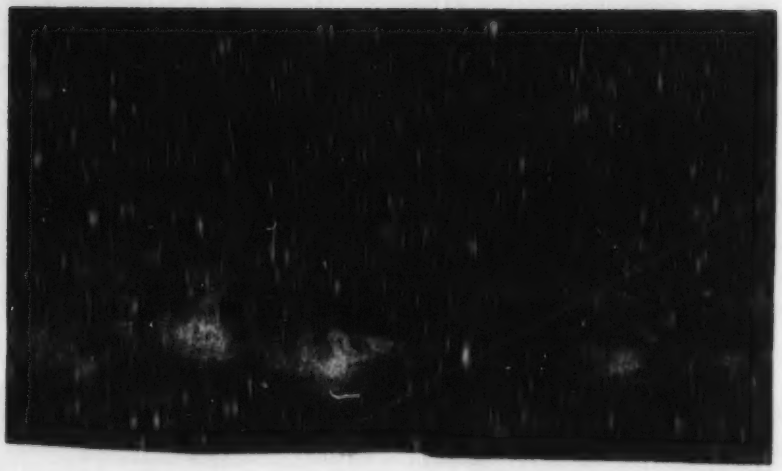

FIGURE 13. FABRIC SEAL WITH METAL WEAR PLATES TO IMPROVE DURABILITY

Plastic Foam Coverings

Another method for controlling hydrocarbon emissions by preventing vapor formation is the use of plastic foam coverings. These are described in detail in API Bulletin 2515(7).

The use of plastic foam involves spraying a foam like blanket over the surface of the stored hydrocarbon liquid, thus preventing the formation of hydrocarbon vapors. According to API 2515, use of foam is limited to crude oil. Its use on gasoline is not effective and causes operating problems. Reductions in emissions of from 70 to 90 percent are reportedly possible over fixed roof tanks with vent-valve settings of 0.5 ounce per square inch of pressure.

Variable Vapor Space Systems

These devices consist of basically two types -- lifter roofs and flexible diaphragms. They can be either separate tanks such as that shown in Figure 14 or integral with a fixed roof tank as that shown in Figure 15.

These systems are primarily designed to limit breathing loss from fixed roof tanks. They are generally used for gasoline storage where tank throughput is low (less than 6 to 12 turnovers per year).

Usually a series of fixed roof tanks are connected to a variable vapor space tank by a series of manifolds. Vapors evolving from the products stored in the fixed roof tanks during periods of thermal expansion or reduced barometric pressure are temporarily stored in the variable vapor space tank. During periods when the vapors are contracting, such as at night, they are transferred back to the storage tanks. In this manner, normal breathing losses are effectively controlled.

Filling losses are also controlled up to the point where the expelled vapor exceeds the capacity of the variable vapor space system. In some cases "balanced pumping" (filling some tanks while other are emptying

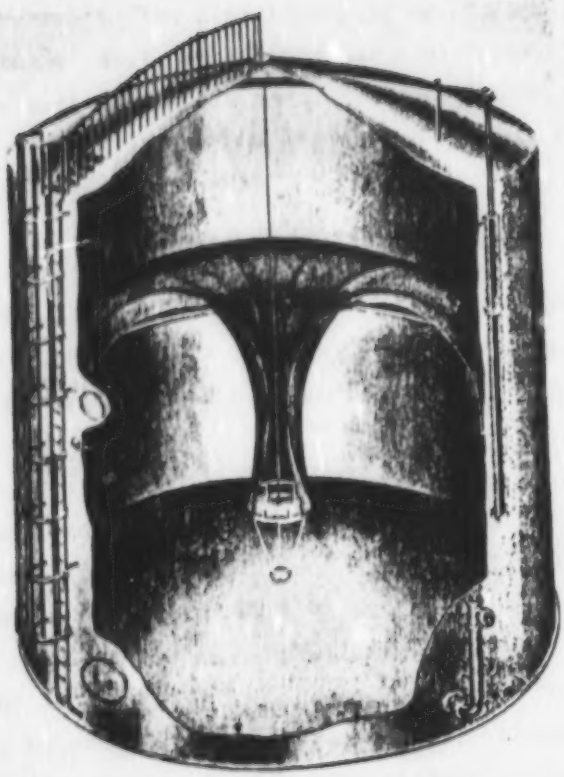

FIGURE 14. SEPARATE VARIABLE VAPOR SPACE TANK

Taken from API Bulletin 2520 "Use of Variable-Vapor-Space Systems to Reduce Evaporation Loss" September, 1964

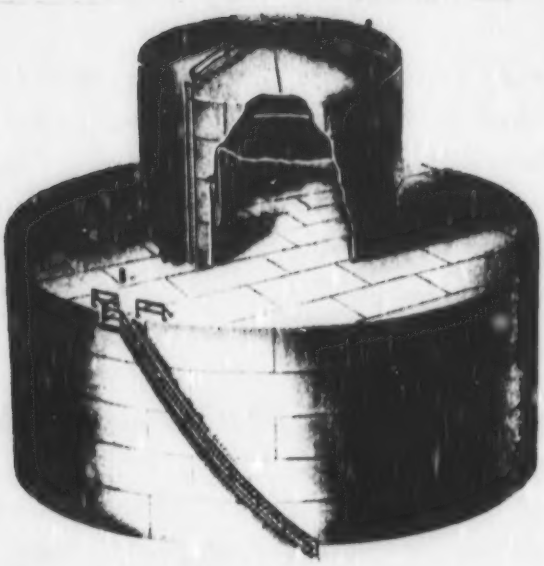

FIGURE 15. INTEGRATED VARIABLE VAPOR SPACE TANK

Taken from API Bulletin 2520 "Use of Variable-Vapor-Space Systems to Reduce Evaporation Loss" September, 1964

on a common manifold) can be used to further control emissions. However, problems with scheduling and preventing contamination of dissimilar stocks limit the applicability of this technique.

Potential points of emissions from these systems are from leakage through manifolds seals and fabrics used for diaphragms, and from exceeding the capacity of the variable vapor space system during filling periods.

Vapor Recovery

Vapor recovery is in effect an extension of a variable vapor space hydrocarbon control system discussed earlier. A key difference, however, is that vapor recovery systems are designed to handle both breathing and working losses while variable vapor space systems alone are designed only to handle breathing loss.

Figure 16 shows a simplified schematic diagram of a modern vapor recovery system design for refinery use. As in a variable vapor space system a battery of cone (fixed) roof storage tanks are connected by a series of gas manifolds to a gas holder (usually a low pressure diaphragm type design).

Provision is made for removing excess gas from the gas holder with a compressor. To make up for this lost gas a blanket gas is allowed to flow into the vapor space of the cone roof tanks during periods of vapor contraction (due to cooling or barometric pressure changes) or during periods of liquid withdrawl. The blanket gas usually consists of either natural gas or boiler flue gas and its purpose is to maintain a non-explosive mixture in the vapor space of the cone roof tanks.

If natural gas is used as a blanket then the vapors recovered from the gas holder represent a high grade combustible fuel gas. This gas may or may not be processed through various stages of refinement such as cooling to condense low volatile liquids separating them from the gas stream as shown in Figure 16. The fuel gas can be used as an energy source for the various gas-fired furnaces in a refinery.

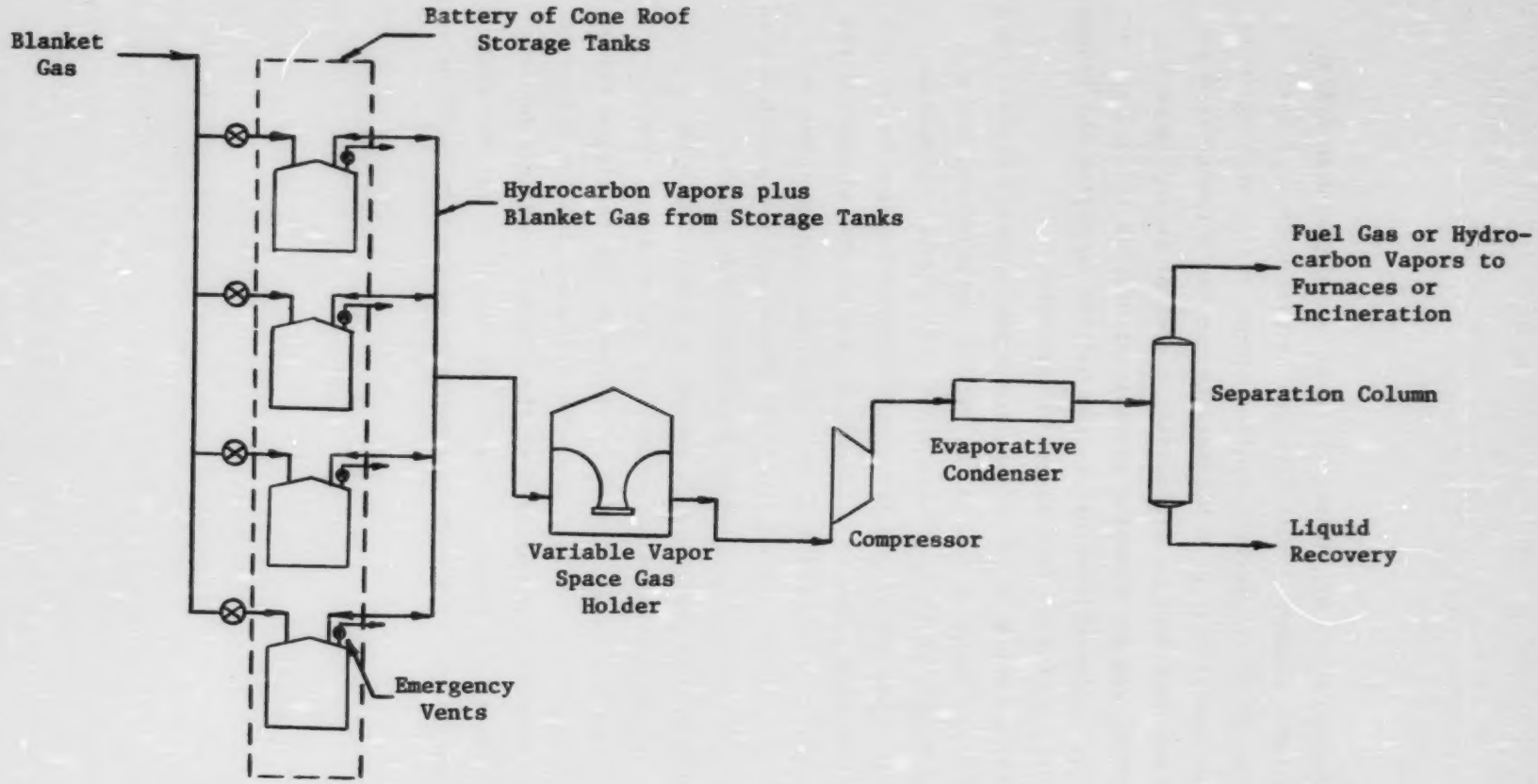

FIGURE 16. SIMPLIFIED SCHEMATIC OF A TYPICAL VAPOR RECOVERY SYSTEM

The Valdez crude oil storage terminal in Alaska uses boiler flue gas as an inert blanket. This flue gas is available from large boilers supplying steam to operate pipeline compressors. When an inert gas such as flue gas is used as a blanket the recovered vapors from the gas holder are not high enough in combustible content to represent a fuel gas. However, the gas contains significant hydrocarbon content and therefore must be incinerated either in the boilers supplying the blanket gas or in separate auxiliary fuel fired incinerators.

The major points of emissions from vapor recovery systems during normal operation are leaks in manifolds, valves, compressors, and gas holders. These leaks can be kept very small with proper maintenance. However, because vapor recovery units are relatively complex mechanical systems, normal operation may be difficult to insure 100 percent of the time. When upsets or equipment failures occur the storage tanks are operated in the same manner as conventional fixed roof tanks with excess vapors being vented through an emergency pressure vent valve.

Vapor recovery systems with secondary processing offer a positive means of hydrocarbon emission control and under normal operation with proper maintenance could be more effective in controlling emissions than floating roofs. Natural gas blanketed systems allow for a form of product conservation in that vapors from the storage tanks can be used as a fuel gas. Inert gas blanketed systems do not allow for the same degree of conservation but do provide for positive control of vapor emissions.

ANALYSIS OF THE VALIDITY OF CURRENT API CORRELATIONS FOR PREDICTING HYDROCARBON LOSSES FROM FIXED ROOF AND FLOATING ROOF STORAGE TANKS

Industry concern for evaporation losses from petroleum storage tanks resulted in a symposium on the subject on November 10, 1952, at the 32nd Annual Meeting of the American Petroleum Institute[1] (Symposium on Evaporation Loss, Proceedings, American Petroleum Institute, Vol. 32, 1952, pp 212-281). The papers prepared by the various committees for this symposium culminated eventually in a series of API bulletins formalizing analytical and computational procedures for estimating hydrocarbon losses from fixed and floating roof type storage tanks containing gasoline and crude oil[3,2]. Some modifications based on observations (generally proprietary) were made to computed results to allow for improvements in design and maintenance. The purpose of this discussion is to evaluate the present day validity of using these equations to estimate hydrocarbon emissions to the atmosphere in modern equipment.

Evaporation Loss From Fixed Roof Tanks (API Bulletin 2518)

There are two losses that were dealt with in the scope of this study -- the breathing loss and the working loss. Breathing loss is defined as "vapor expelled from a tank because of the thermal expansion of existing vapors, and/or expansion caused by barometric pressure changes, and/or an increase in the amount of vapor from added vaporization in the absence of liquid-level change, except that resulting from boiling"[3]. Working losses are defined as "vapor expelled from a tank as a result of liquid pumping into and out of the tank"[3]. The history of the derivation of the empirical relations for both these types of losses will be discussed in turn, along with comments on the validity of the empirical relations as applied to modern technology.

Breathing Loss

A theoretical breathing loss equation as discussed in several references[1,8,9] was developed to foster a better understanding of the mechanism of hydrocarbon losses from fixed-roof tanks. Following these references, we consider a closed container partly filled with a volatile liquid. Then, assuming the perfect gas law for a given mass of air

$$(P_a + P_2 - p_2)\, V_2/T_2 = (P_a + P_1 - p_1)\, V_1/T_1 \quad (1)$$

If the pressure exceeds the vent opening pressure, the loss of volume is given by

$$\Delta V = V_1 \left[\left(\frac{P_a + P_1 - p_1}{P_a + P_2 - p_2} \right) \left(\frac{T_2}{T_1} \right) - 1 \right] \quad (2)$$

Since the liquid volume of the loss is proportional to the vapor pressure of the fuel in the discharged gas, one may put this in the form

$$\Delta G = K \left(\frac{P_1 + P_2}{2} \right) V_1 \left[\left(\frac{P_a + P_1 - p_1}{P_a + P_2 - p_2} \right) \left(\frac{T_2}{T_1} \right) - 1 \right] \quad (3)$$

where K is a function of the compressibility factor and composition of the lost fuel. While a certain factor is recommended for gasoline, as of 1952, the factors would have to be reevaluated for modern gasoline as well as for other fuels.

If $|P_1| \ll P_a$; $|P_2| \ll P_a$; $|p_1 - p_2| \ll P_a$; $|T_1 - T_2| \ll (T_1 + T_2) = 2\,\bar{T}$; $p_1 + p_2 = 2\,\bar{p}$; it is found that

$$\Delta V/V_1 = (T_2 - T_1)/\bar{T} + (p_2 - p_1)/(P_a - \bar{p}) - (P_2 - P_1)/(P_a - \bar{p}).^{**} \quad (4)$$

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* Definition of symbols used in various equations are listed at the beginning of this report.

** Within the accuracy of the assumptions this equation corresponds to the equivalent equation in Reference 8.

If $p = Ae^{-\Theta/RT}$, then to the same degree of approximation as above, and assuming that the variation of vapor temperature is $\beta\,\Delta T$, where ΔT is the ambient temperature change, and the variation in temperature of the fluid surface is $\alpha\,\Delta T$,

$$\Delta V/V_1 = \left(\Delta T/\bar{T}\right)\left[\beta + \alpha\left(\frac{\bar{p}}{P_a - \bar{p}}\right)\left(\frac{\Theta}{R\bar{T}}\right)\right] - (P_2 - P_1)/(P_a - \bar{p}) \qquad (5)$$

Since α may be about 1/10 and β about 5/4,[1] $P_2 - P_1$ = 1-1/2-inches water, and ΔT is the order of 10 C, it is clear that the last term may be dropped, but the first two terms may be about the same order of magnitude.

It should be noted that there are also barometric pressure changes that occur about once a week, with an amplitude of $\Delta P_w/P_a$ of about 1/30. This term should be added directly to $\Delta V/V_1$, giving a value per day of about $(1/210)(P_a/(P_a-\bar{p}))$; this is a small term compared to two of the previously mentioned terms, but somewhat larger than the relief valve term. Since one is subtraction and the other addition, they roughly cancel.

In Reference 1, it was concluded that there was no hope of using Equation (5) because of the large number of variables involved. As a result the basic equation was dropped and resort was made to an empirical analysis of available experimental data.

The basic relationships expressed in the derivation of Equation (5) could possibly be used for guidance in developing a more basic correlation around experimental data.

The next step in developing a basis for analyzing the experimental data would be to derive an equation relating diurnal ambient air temperature variation, solar input*, and wind velocity to the temperature variation of the vapor and the liquid in the tank. If one only writes out the terms for

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* We note that Appendix 4 of Reference 3 (API 2518) presents a detailed treatment of some data on the relation between total reflectance of a tank surface and with bulk liquid temperature relation to that with a white tank and loss relative to that with a white tank. However, no theory is presented.

a steady state transfer of heat to the tank fluid and vapor from the environment, it is clear that convective transfer results in two terms (a constant plus a term depending on the Reynolds number) and solar radiation results in a third term, which depends, among other things, on the finish of the tank. For the diurnal cycle, the heat capacity of the fluid and vapor in the tank must also be considered to determine the loss per day. Obviously, then, the results must be averaged over solar conditions, wind conditions, and temperature. The form for the final equation could have been set up at the time of the formulation of Reference 3 (API 2518), and terms condensed on the basis of qualitative evaluation of terms to permit the presentation of a form of empirical equation to use in correlating the data. Failure of the correlation form would then indicate either a deficiency in understanding the phenomena, the presence of an unknown variable, or a deficiency in the method of determining the data. Mathematically, there is little probability that the loss should be expressed as the first term only in the Buckingham π-theorem derivation[10,11] as is typified by the technique used in API 2518[3]. Because reasonable cost computer capacity is now available that far exceeds that when API 2518 was prepared, sample computations could now be carried out over the range of variables to evaluate the significance of various terms and result in a greatly improved empirical relation.

Experimental data on breathing losses of gasoline were contained in 256 individual tests which were screened down to 178 acceptable tests. Of these, 86 were for nonworking tanks and the 64 of these tests for tank diameters of 20 ft or more (see Table 1) were used to determine the coefficients in the empirical relation for breathing loss.

$$L_y = \frac{24}{1000} \left(\frac{p}{P_a - p} \right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_p C.$$

The definitions of terms in this equation are given in Table 2.

TABLE 1. RANGE OF VARIABLES[3]

D, feet	Number of Tests	ΔT, degrees Fahrenheit	Number of Tests	H, feet	Number of Tests	P, pounds per square inch absolute	Number of Tests
10 to 20	-	5 to 10	6	1 to 2	4	1.0 to 2.9	22
20 to 30	-	>10 to 15	12	> 2 to 5	10	3.0 to 3.9	19
40 to 55	7	>15 to 20	36	> 5 to 10	18	4.0 to 4.9	14
60 to 70	3	>20 to 25	28	>10 to 20	26	5.0 to 5.9	13
100	4	>25 to 34	4	>20 to 30	16	6.0 to 6.9	16
110 to 120	37	---	-	>30 to 40	12	9.0 to 9.3	2

TABLE 2. DEFINITION OF TERMS FOR GASOLINE BREATHING LOSS EQUATION FOR FIXED ROOF TANKS[3]

L_y	= breathing loss, in barrels per year.
P	= true vapor pressure at bulk liquid temperature, in pounds per square inch absolute. Average liquid body temperature usually is available from gaging records; however, if this information is not available, it may be estimated by adding 5 F to the average ambient temperature from meteorological records. (Meteorological data for several locations in the United States and Canada are presented in API Bulletin 2513, Appendix VI.)
D	= tank diameter, in feet.
H	= average outage, in feet, including correction for roof volume. (A cone roof is equivalent in volume to a cylinder which has the same base diameter as the cone and is one-third the height of the cone.)
T	= average daily ambient temperature change, in degrees fahrenheit (difference between U.S. Weather Bureau average daily recorded maximum and minimum temperatures).
F_p	= paint factor, determined from field tests (see Table 3).
C	= adjustment factor for small-diameter tanks.*

* The height to diameter ratios of the smaller tanks are ordinarily considerably greater than for the large tanks, and the multiplying shape factor (C_p) was derived to compensate for the lack of correlation of these data from the smaller tanks (Figure 17).

TABLE 3. PAINT FACTORS (3)

Tank Color		Paint Factor, F_p	
Roof	Shell	Paint in Good Condition	Paint in Poor Condition*
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminum (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	
Medium gray	Medium gray	1.46	

* Values for poor condition provided only as a guide. Factor may be obtained as outlined in Appendix IV of Reference 3.

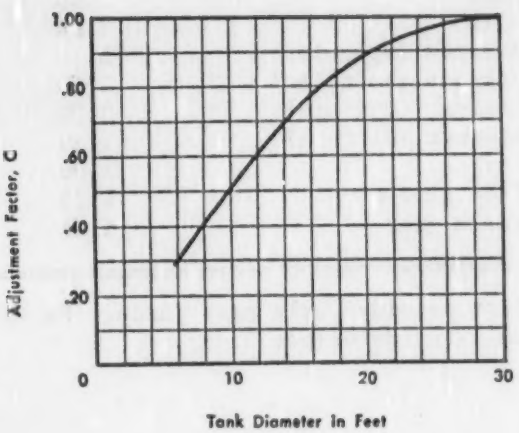

FIGURE 17. ADJUSTMENT FACTOR FOR SMALL-DIAMETER TANKS (3)

Considering the ratio of the observed to calculated value for the 86 tests reveals a Gaussian type distribution on a logarithmic basis, with 68 percent of the points falling within $\pm$ 34 percent of the mean*. This does not appear to agree with the implication of a rather vague statement in Reference 3 that "the calculated breathing loss will deviate in the order of 10 percent from the actual breathing loss".

A close examination of individual sets of data indicated that the factor of 1/2 on H appeared quite good (the significance of 0.51 as compared to 0.5 is highly questionable). The data seemed to indicate that the effect of ΔT should be considered to be linear at low values, and fall off at higher values. With the adjustment factor, the effect of diameter appears to be well represented; however, the need for an adjustment factor shows that the basic phenomena are not all included in the result and make one question the validity of extrapolation to larger sizes. The basic analysis of data discussed in reference to the paint factor (Appendix IV, API 2518[3]) appears to be excellent. However, comments on the actual factors recommended in the text of API 2518 do not reflect the more in-depth analysis of Appendix IV.

The term which includes the true vapor pressure is quite puzzling. The relation $(p/(P_a-p))$ shows up in the theoretical derivation, and appears quite logical to include, however, one notes that in deriving a relation for the liquid volume of fuel loss, as contrasted to the total vapor loss, a vapor pressure term must be included.** On the basis of the theoretical relation, then, one would expect a variation of liquid loss with $p(p/(P_a-p)^n)$ where n is between zero and unity. Furthermore, in API 2518[3], breathing losses from 15 crude oil tests were also studied. The results, to be discussed in more detail later, showed a variation in effect of vapor pressure contrary to what would be expected, comparing gasoline and crude oil losses

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* That 34 percent is half 68 percent is a coincidence and has no intrinsic implications.

** Discussed in more detail in connection with filling losses later in this section.

by using the empirical equations. Using the empirical equation directly results in higher losses for crude oil than for gasoline which is contradictory to expectations. One has a great suspicion that the two contradictions may be related. A cursory inspection of the 64 sets of data reveals that the lowest values of p are associated with the smaller tank diameter, and the highest values of p are associated with the largest tank sizes. This could result in misleading coefficients.

For the correlation of the crude oil breathing loss, 15 sets of data on tanks of 115 to 120 ft diameter were given. Because of the lack of variation in tank size, it was assumed that the same empirical equation held as for gasoline. However, it was necessary to change the coefficient of 24 to 14 to obtain a fit. No satisfactory explanation for the need of the change was given, though both the correlation relations used to go from a Reid vapor pressure to a true vapor pressure curve and the probably slower convection in the liquid fuel were mentioned as possible contributing factors.

Reanalyzing the crude oil data on the basis of the loss divided by the product of true vapor pressure, diameter squared (essentially constant), and average outage, showed no further statistical variation with true vapor pressure or outage. Except for three points, the temperature difference varied too little to consider significant any observed effect.

A comparison of the standard deviations of this set of data, using the recommended correlation from API 2518[3], with the standard deviation for the gasoline data, showed about equal values. However, using the simplified correlation just presented reduced the standard deviation to about half. Including a linear temperature effect (remembering that there were only three points with wide deviations in temperature from the mean) increased the standard deviation to about half way between the two extreme values just mentioned. While this result cannot be used as an argument in favor of a new correlation, it again shows that serious questions can be raised about the validity of the correlating relation of API 2518.[3]

Working Loss (Theoretical Relations)

The calculation of a theoretical relation for working loss is less complex than for the standing loss. As the tank is filled, the vapor above the liquid is displaced out of the tank, the total volume of vapor equalling the volume of liquid pumped, and the vapor carries with it a certain amount of hydrocarbon vapor. Assuming that the vapor is uniformly distributed on an average over the time of filling, the liquid volume of the working loss, F, for gasoline is given by

$$F = 3\ p\ V_W\ K_t/10^4,$$

where V_W is the volume of liquid pumped and K_t is a turnover factor (to be discussed later). For crude oil, the value 3 is replaced by 2.25. This equation for gasoline was arrived at in the following manner. The volume of vapor discharged from the tank is assumed equal to the volume of liquid added to the tank. Using the gas law equation,

$$p\ V = CmRT/M,$$

$$F = m/\rho_L = pV_W\ M/\rho_L\ CRT\ .$$

Comparing this with the previous equation for F, and neglecting for the time factor K_t,

$$M/\rho_L\ CRT = 3 \times 10^{-4}\ .$$

The numerical value was obtained by assuming an average molecular weight for the fuel of 61 and concomitant density and compressibility factors, and a temperature of 60 F. We note that if F and V_w are the same units, the value of the numerical term is not affected by these units.

In Appendix 1 of Reference 3 (API 2518), consideration is given to the working loss from emptying the tank. It is shown that if the tank is emptied in rapid small increments so that equilibrium conditions are attained after each emptying step, the working loss factor F should be increased by the mulitplying factor $(1 - p/P)^{-1}$. This is because there is an inrush of air, part of which (with some fuel vapor) is driven back out as the fuel vapor present approaches equilibrium. If the tank is emptied rapidly, the multiplying factor is $(P_a/p)\ \ln\ (1- p/P_a)^{-1}$; relative to the step-like withdrawal, this factor is a fraction decreasing with increasing vapor presssure. It is noted that with a rapid withdrawal, followed by an immediate refilling, there is no loss due to this effect and the factor should be unity. The same occurs for the case of slow continual withdrawal, maintaining equilibrium conditions in the tank. In the recommended computing procedure[3], an additional factor for these effects is not included. This leads to questions on the validity of the implied confirmation of the theory by observation, discussed below.

The available data on turnover (123 sets) include only 6 tests with 10 or more turnovers per year, with 30 turnovers the largest number. It was felt that the composition in the tank would be near enough equilibrium with turnover more than 10 days apart that the turnover factor, K_t should be unity for these test data. It is commented for gasoline that "For turnovers up to 30 or 40 per year, the data substantiate a value of K_t equal to unity". (API 2518). (From Appendix II of Reference 8 (API 2513), there is an implication that equilibrium saturation may take place in the order of an hour for gasoline.) The important implication is that there was an agreement with the data, although the data are not presented.

The data on crude oil are conceded to be insufficient to permit a formal correlation. Assuming that the reason for the discrepancy between crude oil and gasoline noted with the breathing loss is a result of a slower convective movement in the crude oil, it is assumed that the working loss factor of 0.58 between gasoline and crude oil should be revised upward for use in the working loss case. It is indicated that a review of scattered data led to a selection of a value of 3/4; this resulted in 2.25 replacing 3 in the equation for F.

As pointed out earlier, there were no data on the effect of large numbers* of turnovers of the tank fluid. It was felt that because the tank vapor would not approach equilibrium rapidly, there would be less loss when the number of turnovers was high. It is difficult to reconcile, however, the actual value allowed, which starts to show an effect at about one turnover every 10 days, with implications in other parts of the development that equilibrium is often reached in a few hours. Further, the inclusion of the factor K_t which is unity or less and exclusion of a factor for fill loss discussed above does not seem consistent. In any case, factors for K_t were suggested in Reference 1 but an inconsistency in the values assumed leading to the same total turnover loss per year prediction for 40, 50, and 80 turnovers lead to a modification. It was recommended that $K_t = (180 + N)/6N$ for turnovers N greater than 36 per year. Thus, if V_t is the tank volume, the turnover loss per year for gasoline was given by

$$F + 5 \times 10^{-5} \; p \; V_t \; (180 + N), \quad N \geq 36 \; .$$

A turnover every 2 days would thus nearly double the tank loss per year over that obtained with 36 turnovers per year but would decrease the loss per turnover by one-third. It might be noted that part of the decrease that is required is a result of the overlapping of standing losses and turnover losses as the turnover period approaches the diurnal time.

Evaporation Loss from Floating Roof Tanks (API Bulletin 2517)

From Reference 2 (API 2517), there are two types of loss that are dealt with -- the standing loss and the wetting loss. Standing losses are defined as "those losses other than those resulting from breathing or change in liquid level". For floating-roof tanks, the largest potential source of standing-storage loss is attributed to "an improper fit

* Turnover per year equals the annual throughput divided by the tank capacity.

of the seal and shoe to the shell" (API 2513)[8]. The wetting loss, or withdrawal loss, results from the "vaporization of liquid from a wetted tank wall exposed when a floating roof is lowered by withdrawal of liquid" (API 2513). The history of the derivation of the empirical relations for both these types of losses will be discussed in turn, along with components on the validity of the empirical relations as applied to modern technology.

Standing Loss

The discussion of standing loss indicates that the principal source of evaporation loss is the annular rim space between the tank shell and the outer rim plate. The loss, in the development of Reference 2 (API 2517), was considered to result from evaporation between the seal and tank shell, and vapor permeation through the sealing fabric. Product exposure results from poor fitting seals, shell irregularities, rivit heads, and so forth. It is surmised that any wind helps clear the narrow vapor space and promotes evaporation. The vapor permeability is an additive factor which is considered, in most instances, to be relatively small.

It should be noted that there are other throughts as to the cause of the major portion of the vapor loss, including a diurnal theory which would result in a form similar to that indicated by the theoretical development for fixed roof tanks. This theory presumes that the equilibrium air absorbed in the fuel changes with fuel temperature, as does the vapor pressure of the fuel. As the fuel temperature varies during a day, the periodic outflow of gas through the annular space carries fuel vapor away to be lost.

Sixty tests on tanks were found acceptable and used for analyses in Reference 2. These were divided into the six classes as shown in Table 4.

TABLE 4. DISTRIBUTION OF 60 ACCEPTABLE TESTS BY TYPE OF CONSTRUCTION

Number of Tests	Tank Shell	Type of Roof	Seal	Paint Color
8	Riveted	Pan	Single	White (3), gray (5)
13	Riveted	Pan	Double	Gray or aluminum
9	Riveted	Pontoon	Single	Gray or aluminum
15	Riveted	Pontoon	Double	Gray or aluminum
7	Welded	Pontoon	Single	White (1), gray (6)
8	Welded	Pontoon	Double	Gray or aluminum
60				

Unfortunately, as in the tests on the fixed roof tanks, the assumed condition of each tank is not given. Further, while it was possible to pick out the two cases in which crude oil was used (rather than gasoline), it was not possible to identify the remaining two white tanks that were used. Further, no wind velocity data were given for several tanks in which no loss was found; it is not clear whether the values were not available or were too low to measure.

The analysis of the data apparently was based on a progressive consideration of the influence of various factors, culminating in the empirical expression

$$L_Z = K_f A \left(p/(P_a-p)\right)^{0.7} V_w^{0.7} k_s k_c k_p ,$$

where

$$A = D^{1.5},\ D \leq 150 \text{ ft}$$

$$A = 150^{0.5}\ D,\ D \geq 150 \text{ ft}$$

and the other terms are defined in Table 5.

It was noted that outages and daily atmospheric temperature variations showed no trend; however, if these factors did not cover a wide range of variation, within the accuracy of the data, this observation is not unexpected.

It has been noted previously that the factor $\left(p/(P_a-p)\right)$ enters the reasoning from a consideration of diurnal temperature variations, but a factor p to the first power should be present to account for the change from a gas volume to an equivalent liquid volume basis. Noting as before, that $\left(p/(P_a-p)\right)^{0.7}$ is not too different from p over the range of variables considered, it is seen that such a substitution would be quite logical.

In Reference 2 (API 2517), it is indicated that "twelve tests on similar tanks, 117 ft in diameter with pan roofs and double seals, substantiate the selection of an exponent of 0.7 for the wind velocity"*.

This afforded a good test of the significance of this factor, so, assuming that K_f, k_s, k_c, and k_p were all constant, a standard deviation defined as

$$s^2 = \left(\log \left((L/p^*)/(\overline{L/p^*})\right) - n \log (V_w/\overline{V}_w)\right)^2 /(12-1)$$

was inspected for poth p' = p, and p' = $(p/(P_a-p))^{0.7}$, for a range of values of n about the minimizing value. The two minima were different by less than 1 percent, indicating no preference. But more important, allowing a 5 percent increase in the value of s, i.e., the range of

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* Immediately following is a comment that for velocities less than 4 mph, the values at 4 mph should be used. Actually, no data are tabulated for wind velocities less than 5.0 mph unless the occasional dashes indicate such values.

TABLE 5. DEFINITION OF TERMS FOR STANDING-STORAGE LOSS EQUATION

$$L_Z = K_f D^{1.5} \left(\frac{p}{p_a - p} \right)^{0.7} V_w^{0.7} k_s k_c k_p$$

L_Z = standing-storage evaporation loss, in barrels per year

K_f = a tank-type factor which changes as follows:

- K_f = 0.045 for welded tank with pan or pontoon roof, single or double seal
- K_f = 0.11 for riveted tank with pontoon roof, double seal
- K_f = 0.13 for riveted tank with pontoon roof, single seal
- K_f = 0.13 for riveted tank with pan roof, double seal
- K_f = 0.14 for riveted tank with pan roof, single seal

D = tank diameter, in feet. For tanks 150 ft or less in diameter, $D^{1.5}$, for tanks larger than 150 ft in diameter, use $150^{1.5} \left(\frac{D}{150} \right)$

p = true vapor pressure of the stock at its average storage temperature, in pounds per square inch absolute. (This may be determined from the Reid vapor pressure.)

V_w = average wind velocity, in miles per hour

k_s = a recommended seal factor:

- k_s = 1.00 for tight-fitting seals (typical of modern metallic and nonmetallic seals)
- k_s = 1.33 for loose-fitting seals (typical of seals bult prior to 1942)

k_e = a recommended factor distinguishing between gasoline and crude oil storage:

- k_e = 1.00 for gasoline
- k_e = 0.75 for crude oil

k_p = a recommended paint factor for color of shell and roof:

- k_p = 1.00 for light gray or aluminum
- k_p = 0.90 for shite.

value of n for p' = p was 0.20 to 0.97, which included the recommended 0.7, while the range of values of n for p' defined in accordance with the suggested equation was -0.10 to 0.62. At the most, this exercise indicates a preference for the simpler pressure term if one is convinced the effect of wind is of the order of 0.7. More likely, it only indicates that the scatter of data is sufficiently large and the range of values of wind velocity sufficiently small, that no positive conclusion can be drawn.

A close inspection of the data indicates that there appears to be more than a linear effect of diameter. This could result from a shape factor, as assumed with the fixed roof tanks, but more probably relates to the ratio of the distance of the floating roof below the top of the tank to the tank diameter (especially if there is a real wind effect). It is clear that, with no data on tanks over 145 ft in diameter, the assumption made for tanks larger than 150 ft in diameter has no confirmation.

The values of K_f, relative to each other (see Table 5) are quite reasonable. The imposition of these factors in a plot of the data brings the data closer together, especially in the case of welded tanks relative to the riveted tanks.

The value of k_c for crude oil relative to gasoline is based principally on the value assumed for the working loss for fixed roof tanks, but the two crude oil test results for the pan roof riveted tank, with single seal, appear to confirm the value for this one type of tank. The value of k_s (a seal factor depending on the snugness of fit of the seal) could not be checked on the basis of the data presented in Reference 2 (API 2517)*. The value of k_p, a point factor normalized on the basis of light gray or aluminum, is given as 0.9 for white tanks. This does not check in magnitude with that deduced from the fixed roof

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* Some laboratory tests on losses were discussed briefly, in which loss rates relate to seal gaps were given as 1/8 inches, 1.0; 1/4 inches, 2.6; 1/2 inches, 3.7.

studies, which could certainly be a result of a different balance of phenomena involved in the evaporation in the two types of tanks. Confirmation of a value less than 1 is apparently clear from the data, but only two of the four tests on white tanks are identified, those containing crude oil wherein another difference is also present.

Withdrawal Loss

Quoting from API 2517[2]

"Withdrawal loss resulting from evaporation of stock which fails to drain down the shell as the roof descends is negligible under most conditions. Laboratory data determining the clingage of gasoline to a rusty steel surface support this conclusion. The tests show that clingage ranges from 0.02 to 0.10 bbl of gasoline per 1,000 sq ft of steel surface which has a scale ranging from light rust to dense tight rust.

The loss is represented by the equation:

$$W = 22{,}400 \left(\frac{C}{D} \right)$$

Where:

W = withdrawal loss, in barrels per million barrels throughput

C = 0.02 (based on barrels of clingage per 1,000 sq-ft of shell surface)

D = tank diameter, in feet."

For C = .02, the equation that is given is W = 448/D.

"Withdrawal loss for gunite-lined tanks used for storing gasoline can be significant and should be considered. The laboratory clingage data indicate a factor C = 2.0, which is hundredfold greater than for light rust scale. Since withdrawal loss suppresses standing-storage loss, it is recommended that a factor C = 1.0 be used for gunite-lined tanks used for storing gasoline."

ANALYSIS OF EXISTING API APPROACHES TO MEASURING EVAPORATION LOSS (API BULLETIN 2512)

Accepted methods and measurement techniques to determine evaporation losses from petroleum tanks and transportation equipment are presented in API Bulletin 2512[5]. The bulletin was published July, 1957, by the Subcommittee I of the American Petroleum Institute's Evaporation Loss Committee for general information and is not considered an API standard.

The approaches to measuring evaporation loss can be characterized by any one of the three effects of evaporation: (1) decrease in stock volume, (2) change in stock properties, and (3) measurement of the vented vapors. The approach selected usually depends on whether the tank is in static storage or working service, on the time available for obtaining data, and on the available instrumentation and skill of the personnel performing the test.

Stock Volume Decrease Approaches

Three approaches are discussed for gaging the contents of static and working-service tanks in this section. These approaches are (1) direct manual gaging, (2) liquid metering, and (3) hydrostatic weighing. Direct gaging requires accurate measurements of the liquid level and the average temperature of the stored product. This technique is useful for static storage, no flow to or from the tank. Under working tank conditions when material is either flowing into or from a tank, liquid meters are used to measure the inflow and outflow of material and manual gaging is used to determine the stock inventory. The difference in the metered stock material and manual gaging is attributed to the combined breathing and working loss. The third method uses an auxiliary liquid column or manometer to hydrostatically weigh the contents of the storage container. This method had not been used to any degree at the time of this report, and it was indicated that further development was required. This technique could have many advantages: since weight changes can be magnified with the use of proper instrumentation, shorter test periods can be used, depending on overall sensitivity of the

manometer or pressure measurements instrumentation; and volume corrections for temperature variations are eliminated.

Stock Property Change Approaches

Two methods associated with stock property changes are discussed in API Bulletin 2512 for determining evaporation loss. The two methods are referred to as the "vapor pressure change method" and the "density change method". In principle, the vapor pressure change method involves taking a series of samples of the stored stock from a tank at two different times. From the samples, vapor pressure-evaporation curves can be established. The initial and final pressure-evaporation curves will be displaced from each other because when evaporation occurs (assuming evaporation losses occur between sampling) the more volatile components evaporate at a greater rate than the less volatile. The displacement of the pressure-evaporation curves is a direct measure of the evaporation loss.

The density change method involves taking a series of stock samples from the tank at the beginning and end of a test period. From the initial samples, a density-evaporation curve can be established as a function of the percentage of stock evaporated. The final series of samples taken from the tank are used to determine a final density. The percentage evaporation loss is determined directly from the density-evaporation curve previously established from the initial samples. Both methods require special laboratory apparatus, highly skilled personnel, and truly representative samples of the tank contents.

Vented Vapors Measurement

These methods are applicable only to fixed roof tanks where vapors entering and leaving the tank do so through a small number of well-defined points such as pressure vent valves. Two methods are available for measuring and analyzing the vented vapors. The simplest method is to measure the air flowing in and the vapors flowing out with positive-

displacement (PD) meters. The difference in mass represents hydrocarbon vapors lost. Liquid loss can be calculated accurately with a rough knowledge of the molecular weight of the vented hydrocarbon.

Another method of measuring evaporation loss by analyzing the vented vapors is conducted by measuring the total mass flow of vented vapor and the total hydrocarbon content of the vapor using a hydrocarbon analyzer. The hydrocarbon vapor loss is computed from the meter and analyzer data after correcting for temperature and vapor density.

Special Techniques

Two methods are suggested under the heading of special techniques and are referred to as (1) subscale testing and (2) repeated-transfer technique.

(1) When performing subscale tests, it is essential that proper means be used in scaling the full-scale mechanisms of importance. It is very easy to obtain results from subscale models that are in error when scaled up to the full-scale situations.

Sectional modeling of certain components of the full-scale system in the laboratory can be performed to determine the operational characteristics under various conditions. Care must be exercised in setting up these laboratory tests, also, to ensure that all aspects of importance related to the specific full-scale component are properly accounted for in the laboratory setup.

(2) The repeated-transfer method is a technique to magnify working losses to a measurable level over a relatively short period of time. In this technique, filling and emptying cycles are repeated a number of times to give sufficient stock loss, due to working losses, so that the stock loss is large enough to measure. The use of this technique requires additional equipment for pumping material in and out of the storage container and using one of the techniques specified above to measure the loss of stock material. Corrections must be made for reductions in stock volatility which occur with stock loss sufficient to yield measurable change. These losses, when large enough to measure, would normally and eventually affect evaportation rates.

METHODS FOR MEASURING HYDROCARBON EMISSIONS FROM PETROLEUM STORAGE TANKS

Presented in this section are descriptions of experimental procedures that can be used to measure hydrocarbon (HC) evaporation losses from petroleum storage tanks. Storage evaporation losses have been characterized as breathing losses, standing-storage losses, filling and emptying losses, wetting losses, and boiling losses. A detailed description of each of these loss mechanisms is given in Reference 8. A comprehensive description of a number of methods that have been used or proposed for measuring evaporation losses from petroleum storage tanks is presented in Reference 5. As pointed out in Reference 5, evaporation losses can be determined by measuring: (1) decreases in stock volume, (2) changes in stock properties, and (3) vapors escaping to the atmosphere. The first two measuring techniques, mentioned above, require several months to several years to obtain significant results. This is because of the limitations in accurately measuring small changes that occur in large stock volumes and stock properties with time. The third measuring technique (direct vapor measurements) appears to be an acceptable technique for making accurate short term measurements of emissions from fixed roof tanks but has little applicability to tanks with floating roofs. The only methods used extensively on floating roof tanks in the past for measuring evaporation loss are those described under (1) and (2) above.

A prime objective of this study is to define test procedures for accurately measuring HC emissions from storage tanks that require appreciably less test time than those test procedures that have been used in the past. The primary reason for this objective is: (1) increased ability to correlate important parameters (such as atmospheric effects) with emission rates, (2) reduced time tanks have to be out of service because of testing, and (3) the overall test accuracy can be increased by reducing the test time using the appropriate instrumentation.

Included in this section are descriptions of two test methods, referred to as (1) Enclosure Methods, and (2) Radioactive Tracer Methods, that were considered as possible candidates for making accurate measurement of hydrocarbon losses from storage tanks. These methods are discussed in

terms of their applicability to floating roof tanks (FRT) with external floating covers and to fixed roof tanks with internal floating covers. They are also discussed in terms of their ability to measure hydrocarbon losses through the seal space between the tank roof and walls. Field trips conducted on this study as well as industry contacts have established that this seal space is the major point of hydrocarbon emissions from these types of storage facilities and also the most difficult to control. Field investigations determined that other points of emissions, such as gage hatches and roof supports, could be effectively controlled by various means. Nevertheless, the techniques described in this study could be modified to measure emissions from these points also.

Enclosure Methods

One method of measuring HC emissions through floating roof tank (FRT) seals is to collect and analyze the HC vapors that pass through the seal. In order to collect the vapors, an enclosure must be used over the volume of space above the seal into which the vapors are released. The enclosure should be ventilated to eliminate excessive build-up of HC vapors. There are two ways that can be used to enclose the volume of space above a FRT's seal. One approach is to construct a portable roof that would completely cover the top of the FRT. Another approach is to locally cover the space above the seal by attaching a single piece of flexible material to the roof and inside tank walls near the seal. There are advantages and disadvantages of both covering techniques which will be discussed in the following section.

General Engineering Analyses

Presented in this section are general engineering details for HC emission measurements related to enclosure methods. The results of the analyses are presented in a form such that estimates for a variety of enclosure test configurations can be evaluated. Engineering estimates of the time to reach various HC concentration levels, volume turn over-time, air volume flow rate required to maintain various HC concentration levels and critical flow conditions for good mixing are given in this section.

Enclosure Volume and Concentration Accumulation Time. Figure 18 is a schematic that shows various tank enclosure configuration parameters that will be used in the following analysis. The enclosed volume above the seal for portable roof and local enclosure configurations are

$$V_P = \frac{\pi}{4} D^2 \ell \quad , \text{ and} \tag{6}$$

$$V_L = \frac{\pi}{2} bhD \quad , \text{ where} \tag{7}$$

Equation (1) is for portable roof configurations and Equation (2) applies to local enclosures located at the seal. "D" is the tank diameter, ℓ is the distance between the top of the tank and the floating roof, b is the distance between the tank sidewall and the enclosure attachment point on the floating roof, h is the distance between the floating roof and the enclosure attachment point on the tank inside wall.

Calculated enclosure as a function of tank diameter are presented in Figure 19. As expected, the enclosed volume associated with portable roof configurations are substantially larger than local seal enclosure configurations for floating roof positions greater than 4 feet from the top of the tank. Later in this section, it will be shown that larger volumes are a disadvantage for this type of testing.

The time variation of HC concentration level within the enclosure will depend on the HC emission rate, enclosure volume, and uniformity of mixing within the volume. The rate of change of HC concentration level within a given volume is given by

$$\dot{c} = \frac{\dot{Q}_{HC}}{V} \quad , \tag{8}$$

where $\dot{Q}_{HC}$ is the volume flow of HC vapor, and V is the enclosed volume. Estimates of the time (t_c) required to achieve various HC concentration levels within an enclosure of known volume (V) are presented in Figure 20. These estimates are based on the following assumptions: (1) no leaks in the enclosure covering, (2) there is a uniform mixture of HC vapors and air in the enclosure, (3) the initial HC concentration level is approximately zero at time zero, and (4) the HC emission rate is expressed as a time average value over the concentration build-up time. For a constant volume system, the concentration accumulation times shown in Figure 20 represent estimates of overall system response times and test times. To reduce the test time below 2 hours as shown in Figure 20 the product of the

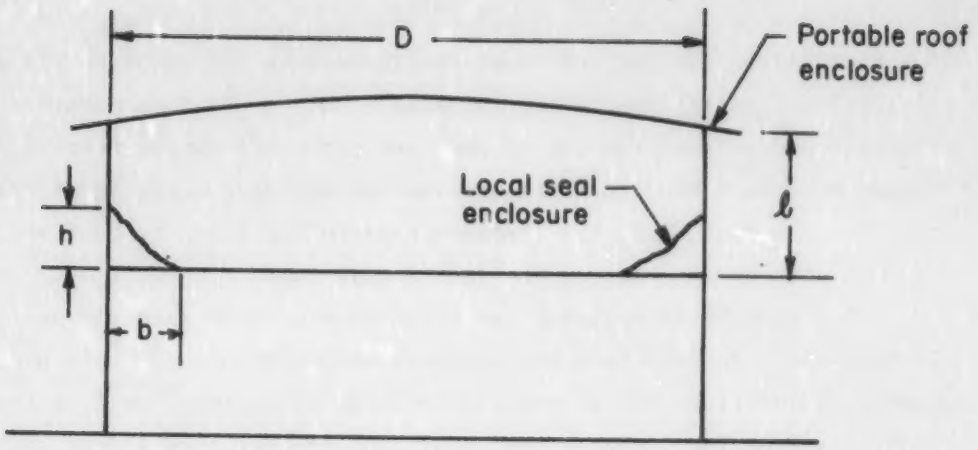

FIGURE 18. TANK ENCLOSURE PARAMETERS

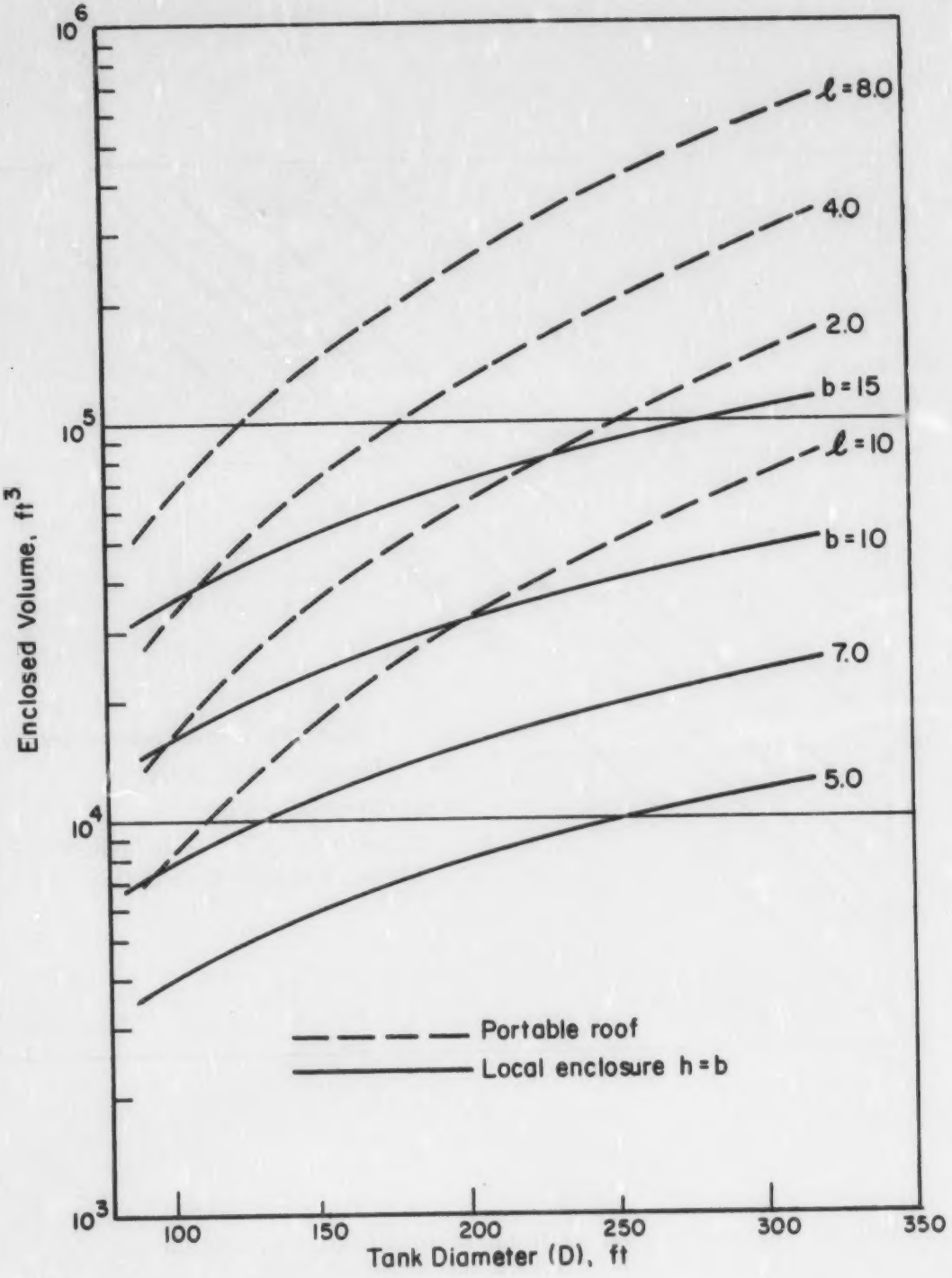

FIGURE 19. ENCLOSURE VOLUME AS A FUNCTION OF TANK DIAMETER

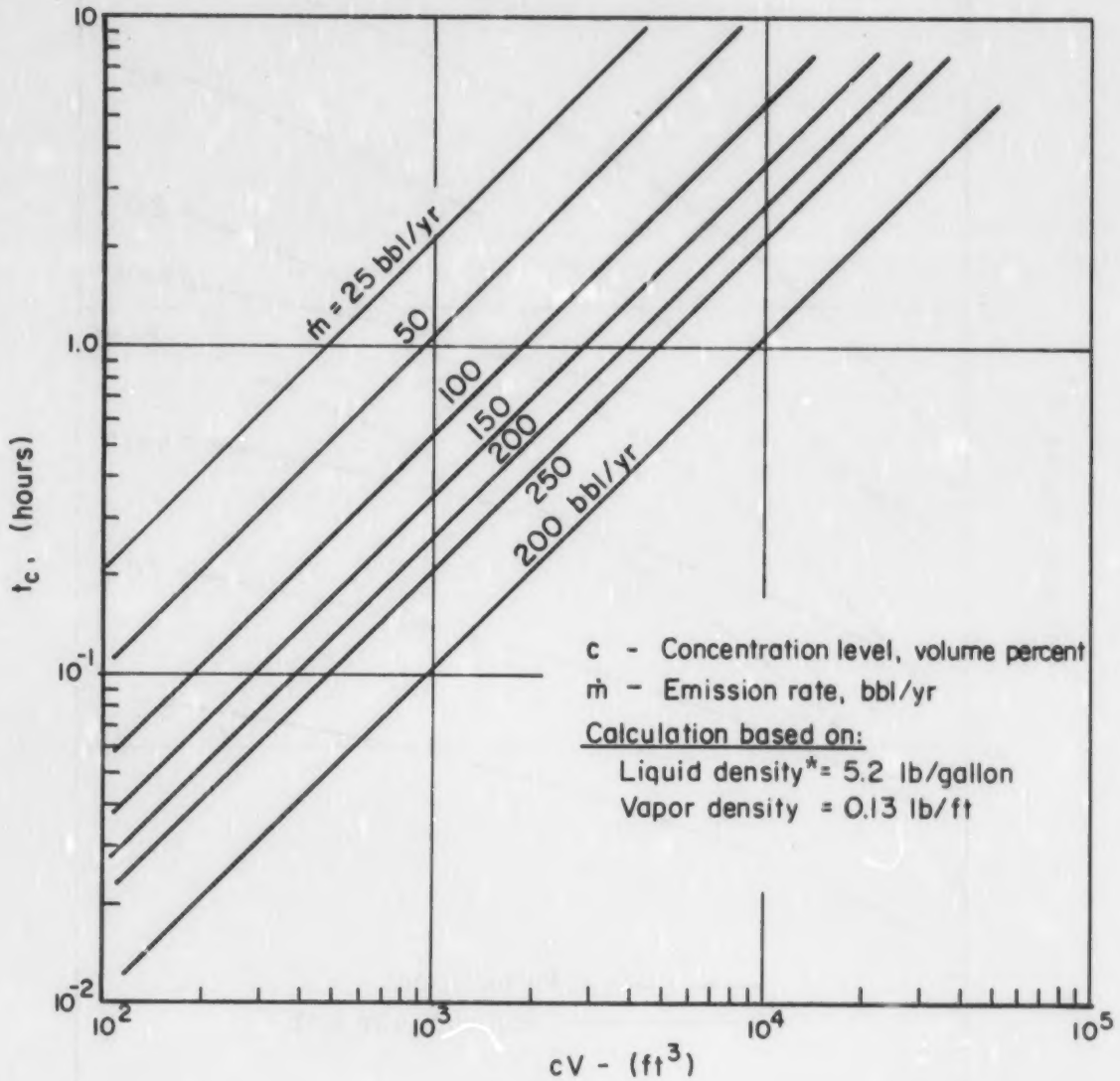

FIGURE 20. ESTIMATED TIME TO REACH VARIOUS CONCENTRATION LEVELS AS A FUNCTION OF VOLUME AND EMISSION RATE

* Density of condensed vapor.

concentration level and volume must be below 10^3 for emission rates of 22 bbl/yr and higher. It should be noted that for a constant cV condition, the accumulation time varies approximately an order of magnitude for emission rates from 25 to 250 bbl/yr.

The general approach of using a constant volume system to collect the HC vapors appears quite simple and straightforward to use in determining emissions. However, there are some apparent difficulties such as: (1) determining the system volume accurately, (2) assuring that a uniform mixture exists, and (3) assuring sufficient control of test conditions to achieve optimum data accuracy.

Steady State Concentration Level in Flowing Systems. The steady state HC concentration level that will be obtained in an enclosure that is continually fed with air will depend on air volume flow rate to the enclosure and the HC emission rate into the enclosure. An estimate of the HC concentration level in a flowing system can be calculated assuming uniformity of the HC vapors and air by

$$\bar{c} = \frac{\dot{Q}_{HC}}{\dot{Q}_{Air}} \qquad (9)$$

where $\dot{Q}_{HC}$ and $\dot{Q}_{Air}$ are the HC and air volume flow rates, respectively.

Estimates of the HC concentration level as a function of air volume flow and HC emission rates are shown plotted in Figure 21 as lines of constant concentration from 100 to 10,000 ppm. The results presented in Figure 21 are for a representative condensed vapor liquid density of 5.2 lb/gal and vapor density of 0.13 lb/ft^3.

The enclosure HC concentration level can be held to less than 1000 ppm for sustained emission rates as high as 1000 bbls/yr with an air supply system that will deliver a maximum 10^5 CFH (see Figure 21). Maintaining the system concentration level well below the flammable mixture limits is important relative to safety aspects of conducting the test. The concentration level in the enclosure can be varied over a wide range by changing the air volume flow rate. For instance at an emission rate of 100 bbls/yr, the concentration level can be varied from 100 to 5000 ppm by changing the air volume flow rate from 10^5 to 4×10^3 CFH.

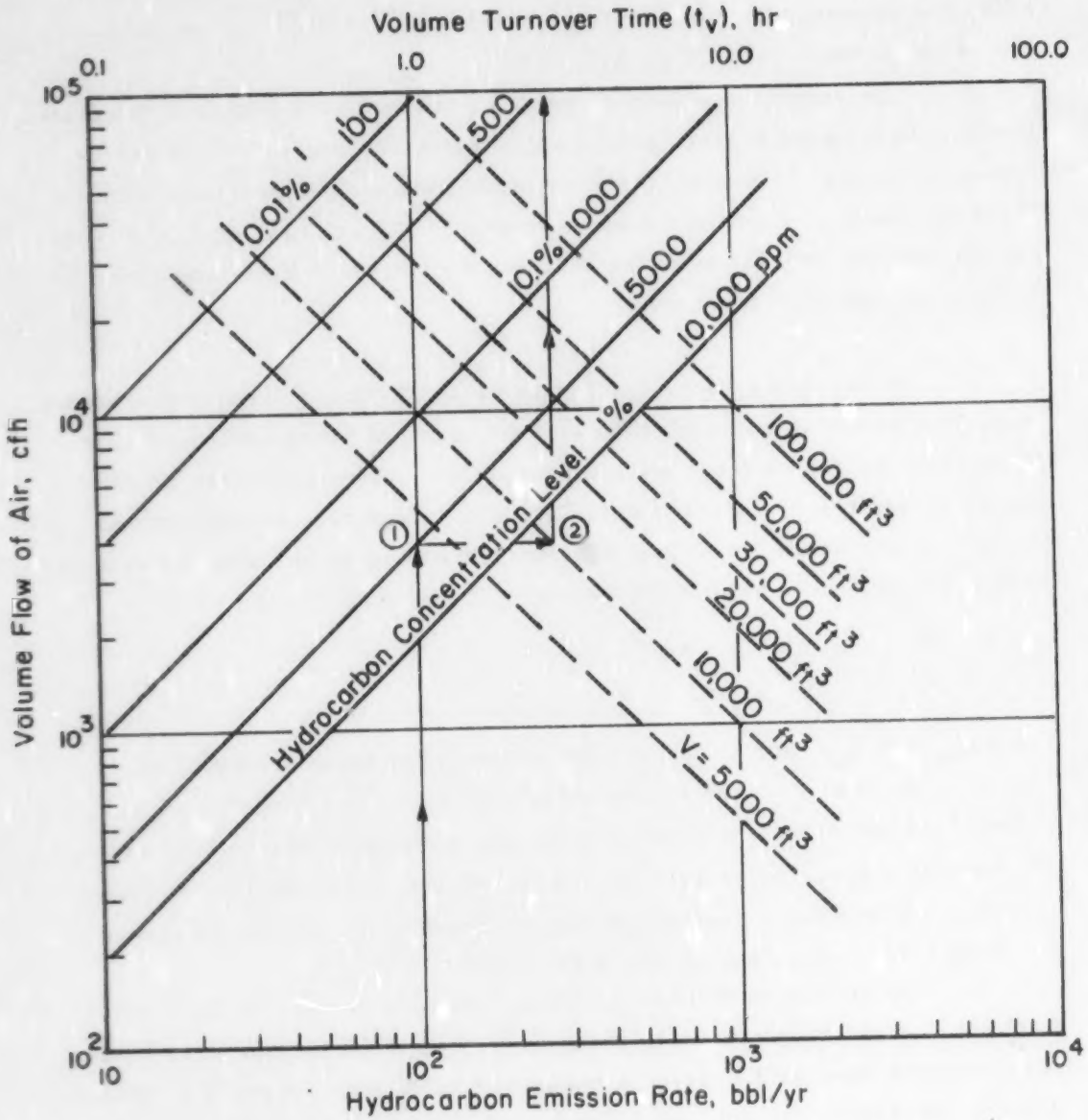

FIGURE 21. VOLUME FLOW OF AIR REQUIRED AND TURNOVER TIMES FOR VARIOUS ENCLOSED VOLUMES AS A FUNCTION OF HC EMISSION RATE

The time required to completely replace the air in the enclosed volume (termed the volume turn over time) is important in determining the total response time of the system. Volume turn over times (t_v) for various size enclosures and air volume flow rates are presented in Figure 21. It is important that the turn over time be minimized to increase the system response to variations in hydrocarbon losses, but at the same time the concentration level must be within measurable range. The data presented in Figure 21 can be used in the following manner to estimate turn over times and air volume flow rates required to maintain desired concentration level for various emission rates. For example, assume the following conditions exist: (1) it is desirable to maintain the concentration level at 0.5 percent due to instrument accuracy, (2) the enclosed volume is approximately 10,000 ft^3, and (3) the HC leak is estimated at 100 bbl/yr. Enter Figure 21 on the 0.5 percent concentration line at a point corresponding to 100 bbl/yr (Point 1). An air volume flow rate of 3800 CFH will be required to maintain 0.5 percent concentration level for an assumed leak rate of 100 bbl/yr. To estimate the turn over time, progress horizontally along the line of constant volume flow corresponding to 3800 CFH, intersecting the line of constant enclosed volume of 10,000 (Point 2). The control volume turn over time can then be read off the upper coordinate in Figure 21, for this case it would be approximately 2.7 hours.

It is obvious from Figure 21 that to maximize system response (minimize turn over time, t_v), the system should be designed with small enclosed volumes and high air flow capability.

Critical Flow Conditions. Sampling of the enclosure gases will be necessary to determine the percentage of HC in the gas mixture. More details of the sampling procedures will be discussed later in this section. For now, it is important to establish flow conditions within the enclosure that will promote good mixing. Since the flow in the enclosure is similar to duct flow, it is possible to define a critical Reynolds number for turbulent flow. Ensuring that turbulent flow conditions exist is a

practical way of promoting the desired mixing of the HC and air. The critical turbulent flow Reynolds number for duct flow is approximately 3000. The Reynolds number for a noncircular flow cross section is defined as

$$Re = \frac{\rho U d_H}{\mu} \quad ,$$

where ρ is gas density, U is mean cross sectional flow velocity, d_H is an equivalent diameter of the flow cross section equal to 4 times the hydraulic radius, and μ is gas viscosity.

For estimating purposes, assume that the enclosure is triangular and also that the height (h) and base (b) are equal, see Figure 18. The equivalent diameter for this configuration is

$$d_H = b/1.707 \quad .$$

The ratio of the gas density to absolute viscosity (ρ/μ) is approximately equal to 6.35×10^3 sec/ft^2. The Reynolds number can be expressed as

$$Re = 7.44 \times 10^3 \frac{\dot{Q}\ (CFS)}{b\ (FT)} \quad , \qquad (10)$$

where $2\dot{Q}/b^2$ has been substituted for the mean cross sectional flow velocity (U) and b/1.71 for the equivalent diameter.

Setting the Reynolds number equal to the critical value of 3000 and solving for the volume flow rate as a function of cross section dimension gives

$$\dot{Q}_L = 1451\ b\ (CFH),$$

where $\dot{Q}_L$ represents the minimum volume flow condition for turbulent flow.

The minimum volume flow rate conditions for various cross section dimensions are shown plotted in Figure 22. It will be shown later that these minimum volume flow boundaries, are not restrictive regarding operational characteristics of various enclosure configurations.

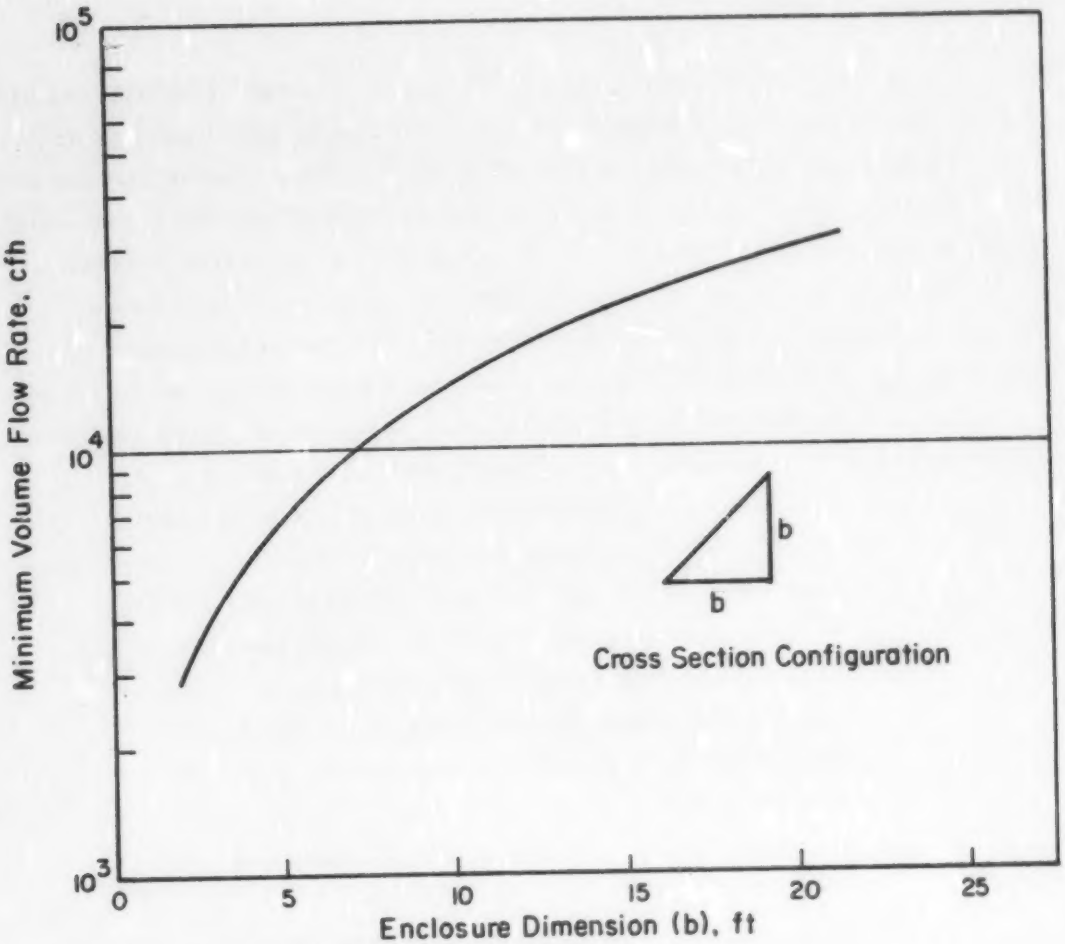

FIGURE 22. MINIMUM VOLUME FLOW FOR TURBULENT MIXING TO EXIST

Enclosure Techniques

As mentioned earlier, there are two basic ways of collecting all the HC vapors escaping through FRT seals, (see Figure 18). Conceptually, the two methods require the installation of a covering either over the top of the tank (portable roof) or locally at the seal location (local enclosure). Based on the results of the preliminary engineering estimates presented in the previous sections, it appears that for large tanks the use of enclosure configurations that completely seal off the space between the floating roof and the top of the tank (portable roof design) would be more difficult to use than local seal enclosures. Specifically, the following disadvantages are associated with portable roof designs:

(1) Concentration accumulation times are long because of large enclosed volumes (see Figure 20).

(2) High volume flow rates of air are required to achieve volume turnover times less than 1 hour (see Figure 21).

(3) High volume flow rates of air result in very low equilibrium concentration levels (see Figure 21) that could lead to overall measurement accuracy difficulties.

(4) Obtaining uniform mixing of the HC vapors and air is more difficult in large volumes.

(5) Construction, installation, and handling of a large covering of this nature would be expensive and difficult.

For the reasons mentioned above, the test procedures outlined in the following section are in general directed toward enclosures that are placed locally over the seal area of the tank. It should be noted that the test procedures discussed in the following section could also be used to estimate HC emission for fixed roof storage tanks that have been fitted with internal floating roofs, as well as for floating roof tanks discussed here.

Preparing a tank will involve installing the fabric material over the seal as indicated above. Specific details concerning the fabric attachment to the roof and tank have not been thoroughly reviewed at this time, based on the results of preliminary discussions with BCL staff members in the Macromolecular Science and Technology Section, it appears that composite flexible fabrics that have low-HC permeability characteristics are commercially available and can be attached to the tank surfaces using an adhesive. There is also the possibility of using magnetic strips as an integral part of the fabric covering which would give additional support to hold the fabric in place while a secondary sealing compound was applied to make the attachment vapor tight. The details and selection of an attachment procedure that can be used easily and quickly to install and remove a covering is left for the final engineering test design analysis.

Two test methods referred to as Rate of Change and Steady-State Methods are discussed in the following subsection for estimating HC emissions. Both methods require measurement of HC concentration levels in HC/air mixtures.

Rate of Change Method

The rate of change method is a direct way of measuring HC emissions through FRT seals. This method hinges on the assumption that an effective, leak-tight covering can be constructed over the FRT seal. It is anticipated that the enclosure will be well ventilated using a blower system which has sufficient flow capacity to initially maintain a relatively low HC concentration level in the enclosure. Air ventilation of the enclosure is desirable during periods when tests are not being conducted to control and maintain HC concentration levels below a flammable limit.

Figure 23 is a schematic of a proposed flow system configuration that could be used to perform rate of change tests. When tests are in progress, valves ① and ③ would be closed and gas vapors in the enclosure

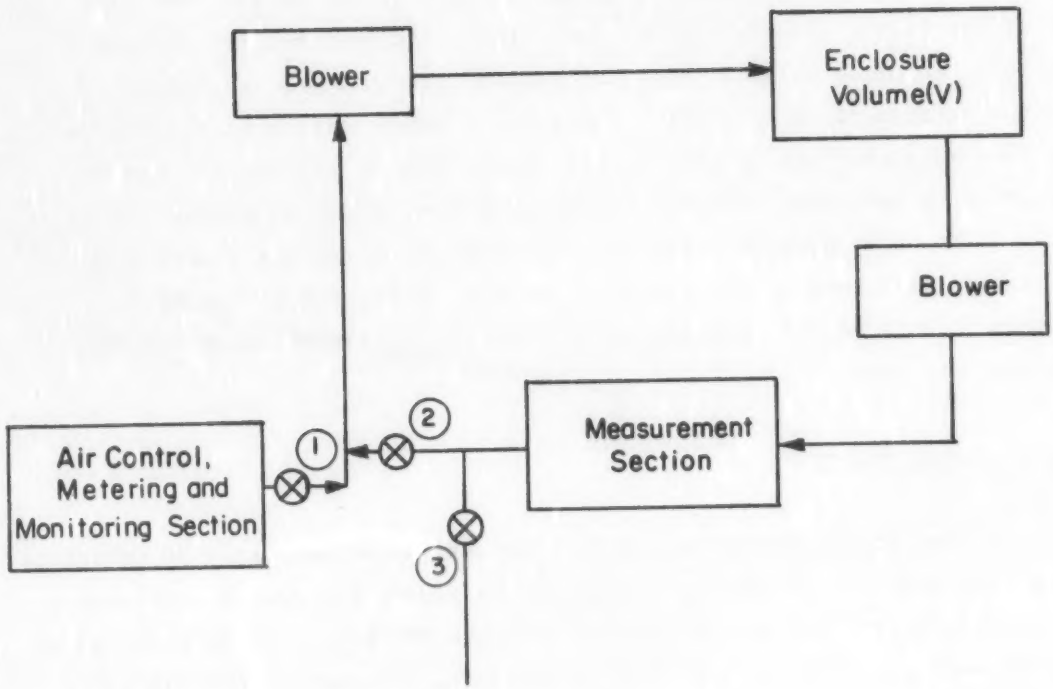

FIGURE 23. SCHEMATIC OF FLOW SYSTEM

would be circulated by the blower to promote mixing in the enclosure. Recycling of the enclosure gases has the additional feature that gas sampling can be performed at one station. If air was not circulated through the enclosure, gas sampling at a number of locations in the enclosure would be necessary to obtain a representative time history of the HC concentration buildup which would sequentially be used to estimate total HC emission losses. If makeup air is required, valve ① would be opened to feed a controlled amount of air to the blower. When tests are not in progress, valve ② would be closed and valves ① and ③ opened to feed fresh air through the system.

Gas sampling measurements can be performed in either the blower's exhaust or intake line. A section of pipe will be used with appropriate probes positioned within the pipe to monitor the HC concentration level. Gas composition will be determined at various times during the test using gas chromatography methods. Depending on the quantity of gas required for gas composition analysis, air may be vented into the recycling system in controlled amounts.

Steady-State Method

Although the rate of change method is a fairly direct way of measuring HC emission rates, it is necessary that the total system volume be accurately known (refer to Equation 8). The test procedures can be slightly modified to eliminate the requirement of determining the system volume. The suggested test arrangement for the Rate of Change Method shown schematically in Figure 23 can be used to perform the tests in the proposed Steady-State Method.

In this method, it is necessary to supply atmospheric air to the enclosed volume at known flow rates. Referring to Figure 23, this can be accomplished by closing valve ② and opening valves ① and ③. Atmospheric air to the blower is controlled, metered, and monitored for HC concentration upstream of the blower as shown in Figure 23. The

exhaust gases from the enclosure flow to a Measurement Section and then to atmosphere through valve ③. The HC vapors are collected and uniformly mixed with the air flowing through the enclosure. At the Measurement Section, the HC concentration level in the exhaust gases and the gas flow rate are measured. These two measurements are the only data required to perform a total HC emission rate calculation. It is anticipated that the volume flow rate of air to the enclosure can be held constant with time. There should not be any major oscillations or variations in this quantity. Therefore, the only variable that should vary with time is the HC concentration level (excluding any atmospheric variations that may occur). It will probably be necessary to time-average the concentration data over some increment of time (5 to 60 minutes). This can be done efficiently by electronic means so that on-line results can be reviewed while a test is in progress.

The quantity of air flow supplied by the blower and the HC emission rate will affect the HC concentration level in the exhaust gases from the enclosure. Estimated HC concentration levels for various HC emission rates and quantities of air flow are shown cross-plotted in Figure 21. Based on published estimates of tank emission factors of approximately 10 to 300 bbl/yr and a supply of air at 10,000 cfh, the HC concentration level will vary from approximately 100 ppm to 5000 ppm. Supplying the measuring air flow rates of approximately 10,000 cfh and measuring HC levels over a range of 100 to 5000 ppm during field testing is well within state-of-the-art technology. For instance, Beckman Hydrocarbon Analyzers are capable of accurately measuring HC concentration levels over a range of 1 to 250,000 ppm.

The system time constant and/or system response time is a function of the size of the enclosure and the volume flow rate of air delivered to the system. Calculations of the time required (t_v) to supply equivalent volumes of air equal to the enclosure volume were performed and the results are presented as cross-plots in Figure 21. The so-called turnover time (t_v) calculations were discussed in the General Engineering Detail Section. In

order to minimize the system response time, the air flow through the system should be maximized and the enclosure volume minimized. In the process of minimizing the system response time, care must be exercised to ensure that the estimated HC concentration level is in a measurable range with respect to instrumentation that can be used during the conduct of field experiments. Based on the data presented in Figure 21, it appears hat system response times on the order of 1 hour or less can be achieved. In comparison with other testing techniques, this would be a dramatic reduction in the elapsed time required to perform a FRT emission measurement. A reduction in test time from, say, weeks to hours is substantial and would greatly influence the accuracy of any correlations done on the test data.

Based on the estimated system response time for an enclosure constructed over a FRT seal, it appears possible that daily, cyclic emission profiles can be obtained. It is anticipated that hourly data measurements will be suitable for determining emissions losses over this period of time. This has not been possible in the past because of the lengthy time period required to perform a test. The data obtained using the proposed enclosure method would also lend itself quite nicely to performing accurate correlations with other test parameters (mostly atmospheric and tank conditions).

Figure 24 is a compilation of the results presented in the General Engineering Analysis Section that shows a system operating envelope for the Steady-State Method. The boundaries of the envelope are consistent with the following: (1) minimum HC concentration level of 100 ppm, (2) maximum HC concentration level of 1000 ppm, (3) minimum volume flow based on enclosure cross-sectional dimension and critical flow Reynolds number, and (4) maximum blower flow capacity. Also, implicitly included in this envelope are the conditions of system time response of less than 1 hour, and maximum enclosure volume of 50,000 ft^3.

Windage Simulation

As mentioned earlier, enclosing the space above the seal isolates the seal from flow eddies generated by natural atmospheric winds blowing

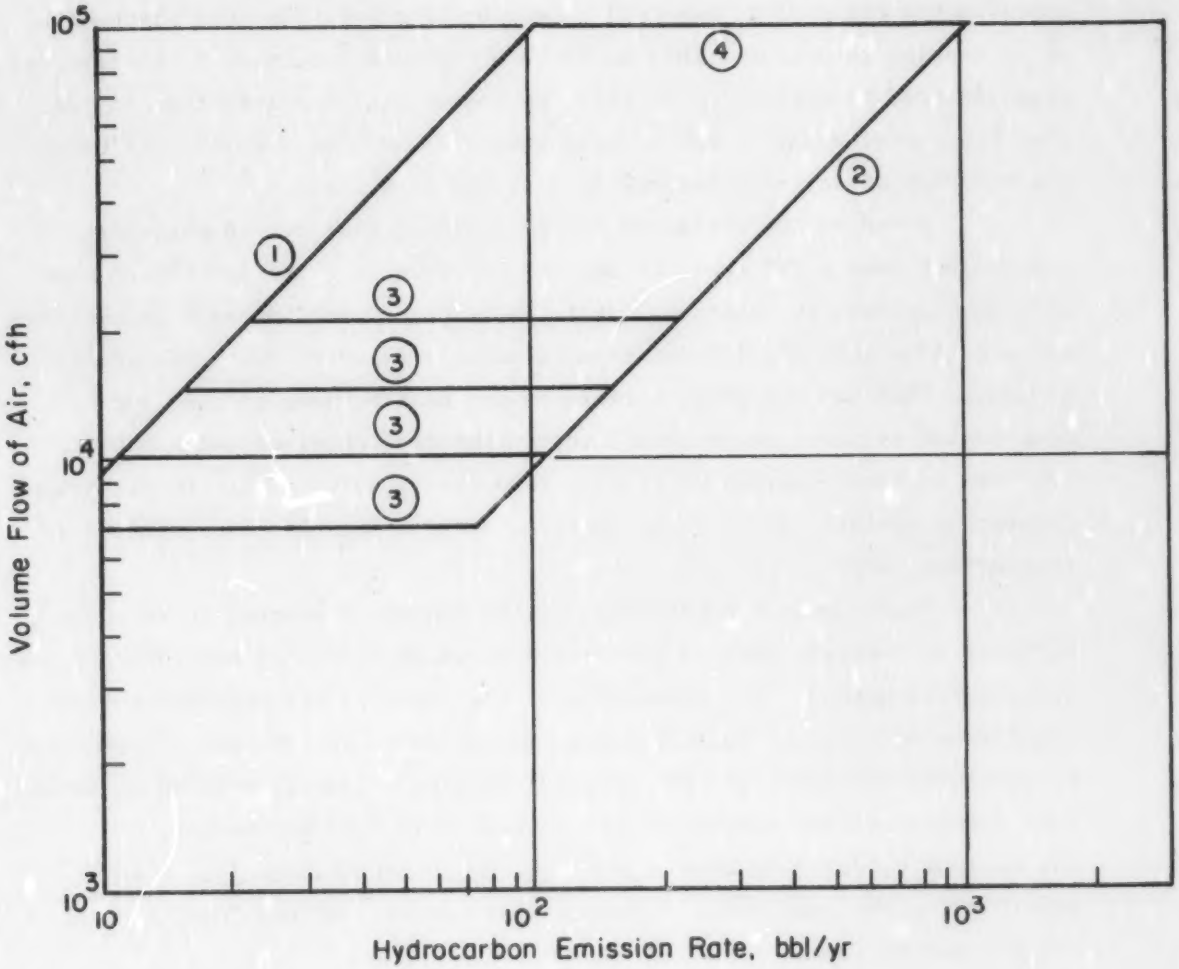

FIGURE 24. ENCLOSURE SYSTEM OPERATING ENVELOPE

over the tank. The influence of flow currents at the seal on emissions is not known at this time. The results related to windage presented in API Bulletin 2517[2] are not detailed enough to accurately establish windage effects.

In the proposed enclosure techniques described above, it will be possible to vary the flow velocity in the vicinity of the seal by varying the quantity of air flow through the enclosure--Figure 25 is a plot of average flow velocity as a function of air volume flow rate for various size enclosures. The boundary curve shown in Figure 25, labeled critical Reynolds number condition, represents the minimum conditions for volume flow and flow velocity for turbulent flow to exist in various size enclosures. The system should, therefore, be operated at flow conditions that lie to the right of the critical Reynolds number boundary to promote good mixing of the gases (air and HC vapors).

Volume flow rates of air over a range from 10^4 to 10^5 cfh with an appropriate blower system can easily be achieved; therefore, it is readily possible to vary the duct mean flow velocity over a range approximately 0.1 to 1.0 fps (see Figure 25) for various size enclosures.

It is anticipated that a test series would be performed to determine if the emission rate varies with changes in mean flow velocity through the enclosure. The results of such a test series would have an impact on estimating the influence of eddy currents near the seal.

Additional Data Requirements

Additional data will be required during tank emission loss tests to perform correlation analyses. Atmospheric conditions such as temperature, barometer, wind velocity and direction, and solar radiation will be obtained simultaneously with the emission measurement. These measurements are more of a routine nature and therefore specific details are not included.

Data related to the tank such as type of tank, seal design, external surface condition, and internal wall condition will also be recorded. Specifying the contents of the tank will also be necessary.

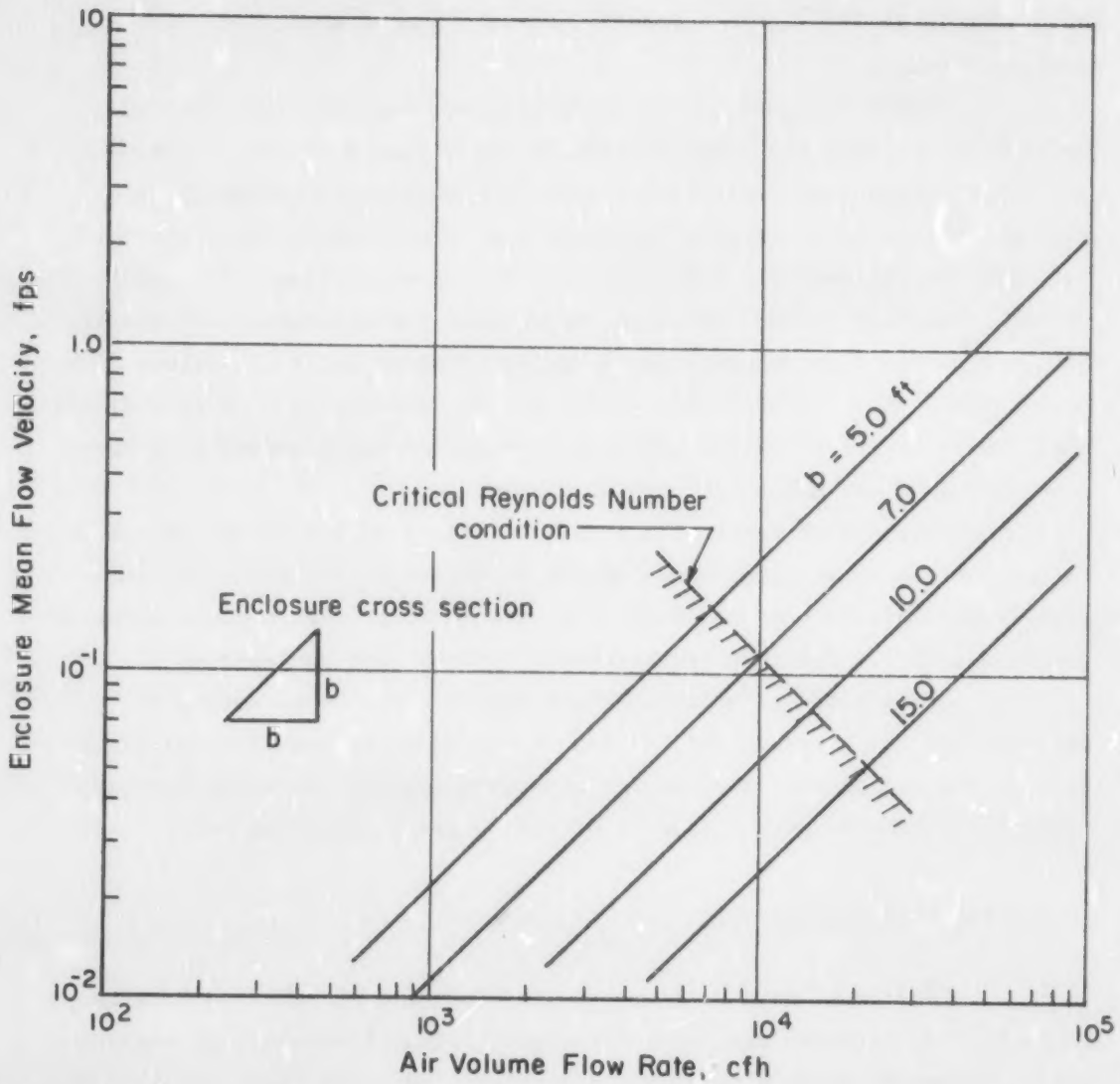

FIGURE 25. MEAN FLOW VELOCITY IN VARIOUS SIZE ENCLOSURES

Appropriate temperature data from the wall and roof of the tank and the stored product will be obtained as deemed necessary. Specification of the actual location for thermocouples is premature at this time.

Tracer Methods

Tracer methods were also evaluated as a means of measuring emissions of hydrocarbons from petroleum storage tanks. The particular tracer method developed would involve injecting a known amount of tracer gas into the vapor space below the primary seal of the floating roof cover and then measuring the depletion rate of the tracer gas. In this way the known amount of tracer gas satisfies the same purpose as the known volume enclosed above the seal in the enclosure method discussed earlier.

Such techniques have certain inherent advantages such as minimizing the amount of modification necessary to the source, eliminating interferences from other emissions sources near the one being tested, and eliminating the need for obtaining vapor samples to determine vapor compositions that are required for interpreting and analyzing measured data taken in the enclosure method approach.

However, these techniques also involve certain inherent disadvantages. These can be summarized as follows:

(1) A tracer gas must be selected that is similar to the hydrocarbon in diffusional or transport characteristics, insoluble in the liquid to ensure that all tracer that is lost to the atmosphere, and capable of being detected separately from the hydrocarbon with a minimum of interference. An example of such a gas would be krypton, although the solubility of krypton in petroleum liquids is unknown.

(2) When several tests are to be run in a relatively short period of time, care would have to be taken to minimize interferences from previous runs. If a radioactive tracer such as krypton were used the radioactive life (reported as half-life) would have to be selected consistent with desired test times.

(3) Any tracer method employed would be an indirect method of measuring emissions. Arguments are bound to exist over the similarity of emissions of tracer gas to those of the hydrocarbons that are the purpose of the test. The only way to resolve these arguments would be to compare the results of the tracer tests to those of more basic and direct methods such as the enclosure method described earlier.

Optical Techniques for Measuring Hydrocarbon Emissions

General Discussion

The monitoring of storage tank emissions centers on detecting the presence of gaseous species above the tank seal or their loss from the vapor space above the liquid product. Both the enclosure and tracer method discussed previously can be used with conventional gas detectors for measuring hydrocarbon or tracer gas concentration. Such analyzers (such as the Beckman hydrocarbon analyzer) are well accepted and are extremely accurate over the range of concentrations expected to be encountered. Optical methods are another means of providing this detection. The general test procedure and data reduction process would be identical to that used in other detection methods. The difference being that output from optical sensors rather than other type sensors would be analyzed as a function of time.

Optical techniques, in general, have several advantages over other types of detectors that might be used to monitor hydrocarbon or tracer gas emissions. Often laser beams are used in optical analysis. Using mirrors to reflect the light around in a specific space, a large area can be covered using a single source and a single detector. This type of system would offer the best possibility for long term instrumentation stability compared to a multi-detector approach. Also, since the laser can be tuned to a specific wavelength, the possibility exists for increased detection sensitivity for a broader range of specific gaseous

species that might be considered for hydrocarbon or tracer gas constituents. This degree of selectivity could be quite useful when attempting to monitor the emissions from one type of product in the presence of interference from dissimilar product emission sources. Of course, the interference from like product sources would still be present. However, tunable lasers could also be used to detect a greater variety of tracer gases. This could prove important since solubility not detectability may be the driving force behind picking a particular tracer gas. The possible disadvantage to using optical techniques might be cost and ease of setup. Also, interference from sunlight might occur. However, those factors would have to be weighed against the advantages of using optical methods and the cost and complexity of comparable systems utilizing other detector techniques.

Details of Apparatus

Several optical detection methods are applicable to tank emissions monitoring. The more promising techniques are

- Direct adsorption of light by gaseous species
- Differential absorption
- Induced fluorescence.

Other optical techniques have possible application but would be more difficult to apply in a field environment. Of the three techniques mentioned above, the differential absorption method offers the most probable chance of success. In this technique a single beam can be utilized as the light source. This beam consists of radiation at two distinct wavelengths (see Figure 9). One line at wavelength, λ_{ON} is at the absorption wavelength of a particular gaseous species. The other nearby wavelength, λ_{OFF}, is not directly absorbed by the molecule of interest. However, the second beam is attenuated by particulate (in solid and aerosol) matter in the test region due to gross absorption and scattering. These unwanted effects are also present in the absorbed beam. Hence, by subtracting the two beams (i.e., differential absorption), the desired measurement of gaseous absorption can be accurately obtained.

Besides correcting for particulate and molecular scattering as well as particulate absorption, this differential absorption technique can be somewhat self-calibrating. As Figure 26 shows, the use of a chopping wheel with various light filters can provide four distinct frequencies for each off/on-in/out combination. Hence, a single detector with frequency tuned amplifiers can be used to monitor intensities $I_{OFF,OUT}$, $I_{OFF,IN}$, $I_{ON,OUT}$, and $I_{ON,IN}$. The amount of absorption can be calculated from

$$\text{Absorption} = \frac{I_{ON,IN}}{I_{ON,OUT}} - \frac{I_{OFF,IN}}{I_{OFF,OUT}} \quad . \tag{11}$$

Using the setup in Figure 9 and Equation (6), the effects of source intensity drift and detector sensitivity variation can be accounted for automatically.

Application to Storage Tank Emission Analysis

To apply the differential absorption technique to storage tanks, two modes must be considered. These are generally separable into "above" and "below seal" application. Above the seal, a single source consisting of one or more tunable lasers can be used with a single detector as shown in Figure 27. A series of mirrors could be used to traverse the beam around the circumference of the seal. Gaseous emissions from the vapor space will be detected the moment they occur at any point where an emission vapor cloud intersects the laser path.

Also, the integrated absorption along the entire path will be indicative of the total amount of emissions leaking by the tank seal. The monitoring of total integrated absorption with time will yield information on the total leak rate past the seal.

Below the seal, the optical setup shown in Figure 27 would be difficult (if not impossible) to construct. In this case, a compact double or multipass source detector combination would be more applicalbe as

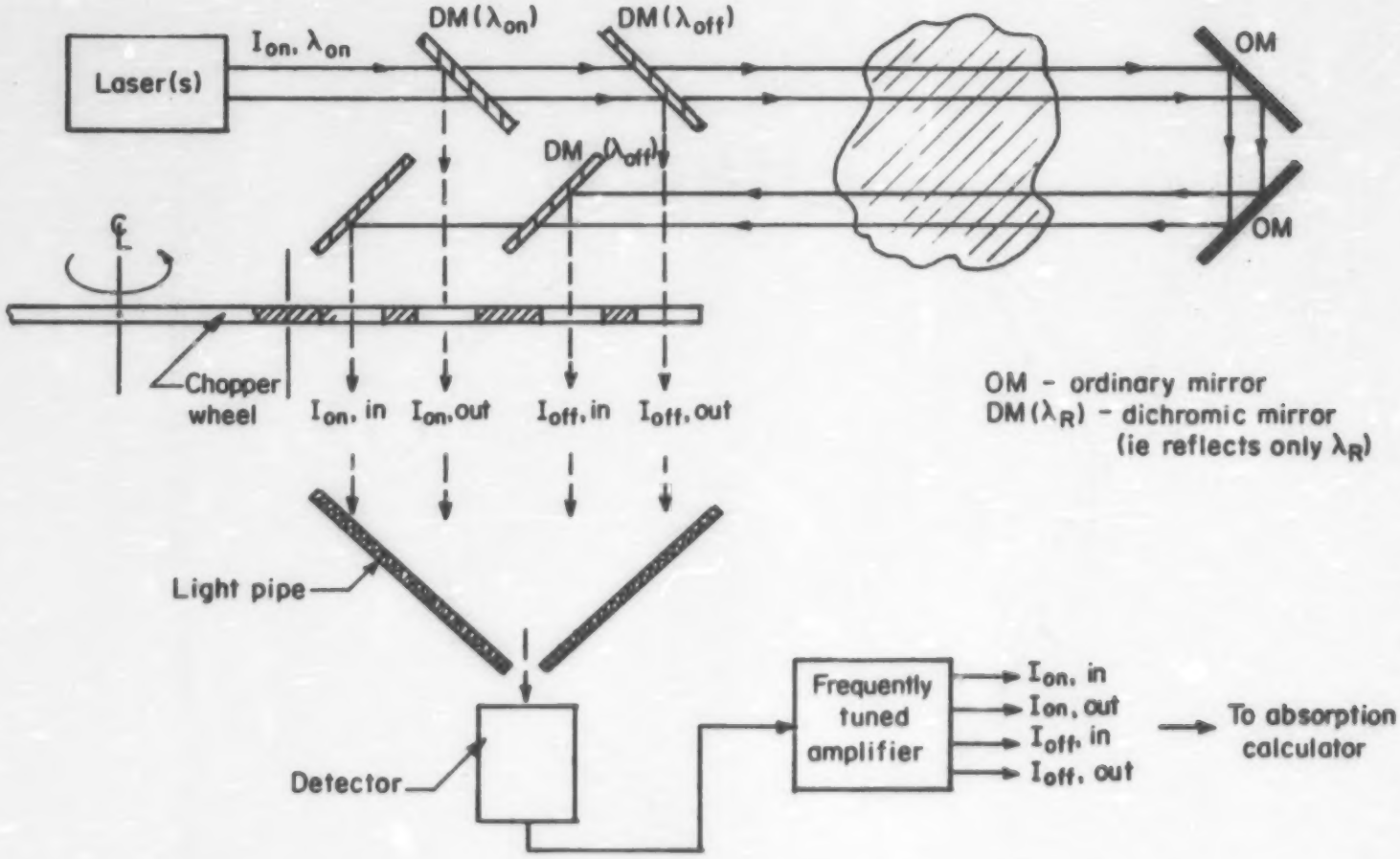

FIGURE 26. BLOCK DIAGRAM OF DIFFERENTIAL ABSORPTION APPARATUS

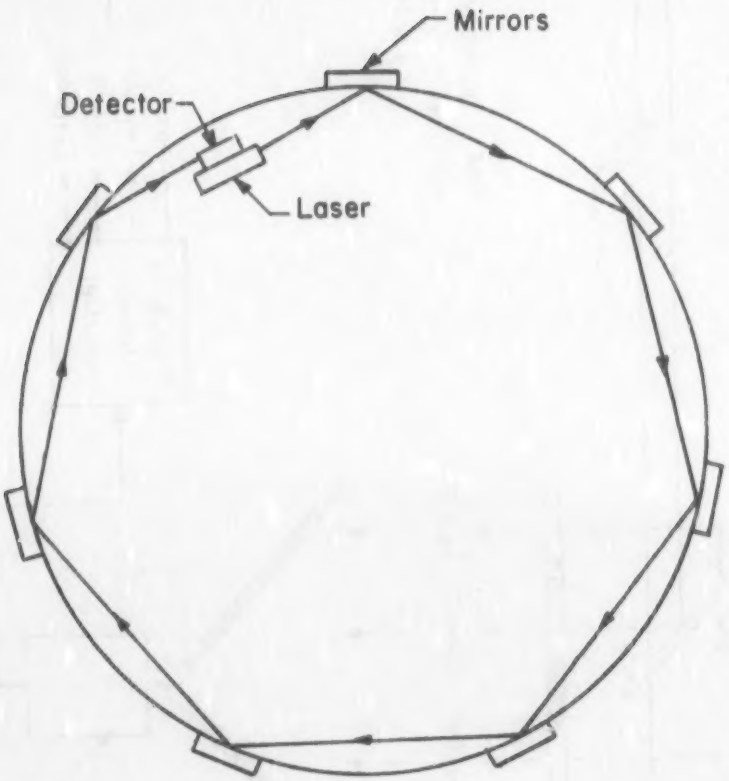

FIGURE 27. ABOVE THE SEAL OPTICAL DETECTION SYSTEM

shown in Figure 28. Due to the short path length, a lower intensity source could be used for below seal applications. Also, daylight interference would be nearly eliminated.

A particular laser detector combination that looks promising for tracer gas detection is a CO_2 laser with line selecting capability coupled with a liquid nitrogen cooled, gold-doped germanium detector. The tracer gas could be sulfur hexafluoride SF_6 which has low solubility in hydrocarbon fuels. The CO_2 laser has several lines which are absorbed by the SF_6 and others that are not. Rapid switching from line to line is possible using acusto-optic translator systems. All the above are off-the-shelf components, so such a system could be put into operation with minimal development costs.

Applications of differential laser absorption techniques to hydrocarbons themselves is more difficult at this time. Some work is under way on diode lasers which would be tunable in the correct wavelength region to obtain absorption from many hydrocarbon fuels. Other laser hydrocarbon absorption combinations are

- He-Ne 3.39μ line for CH_4
- CO_2-10.53 line for C_2H_4
- Iodine laser 3.93 line for C_4H_{10}.

For the iodine laser at 3.93 μm, the C-H bond is measured. Therefore, the absorption at this wavelength is indicative of the total amount of gaseous organic material in the laser beam path. A more in-depth study of these specific lasers should be undertaken in order to assess their applicability for differential laser absorption measurements.

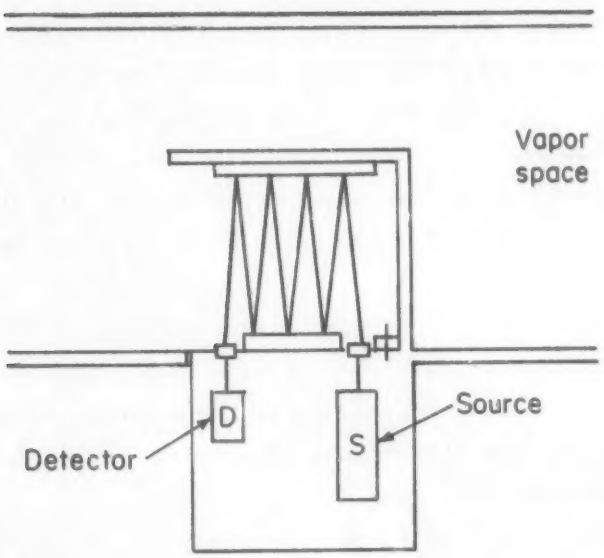

FIGURE 28. BELOW THE SEAL OPTICAL
DETECTION SYSTEM

CONCLUSIONS

- **Current Techniques for Controlling Hydrocarbon Emissions from Petroleum Storage Tanks**

  (1) The floating roof tank - with either external or internal floating roof - is by far the most widely used device for controlling hydrocarbon emissions from petroleum storage tanks. Advances in roof design have been directed at improved safety, durability, ease of construction, and low cost. No experimental data were found to indicate that any particular design (whether new or old) was more effective at controlling hydrocarbon emissions than any other design.

  (2) The most notable advances in floating roof design have been in the seals between the roof and tank wall. The trend has been to highly flexible, resilient fabric seals that have greater ability to conform to irregularities in the tank walls than conventional mechanical seals. These seals can be employed in single stage or in some recent designs in two stage combinations. However, no experimental data were found indicating that any particular seal was superior to any other in controlling emissions. Claims as to seal effectiveness are based on appearance and apparent closeness of fit between the seal and tank wall.

  (3) Vapor recovery offers the potential for positive control of hydrocarbon emissions from storage tanks. However, these systems are complex compared to floating roofs and their effectiveness at controlling emissions is contingent upon their operating dependability. If the recovered vapors can be used as a fuel gas or condensed to liquid form vapor recovery offers the potential for product conservation similar to floating roofs.

- **Analysis of Current API Correlations for Estimating Hydrocarbon Emissions from Fixed and Floating Roof Tanks**

  (1) In neither the fixed roof (API Bulletin 2518) nor the floating roof cases (API Bulletin 2517) were basic phenomenological or theoretical considerations used in developing the correlations of hydrocarbon losses. The equations developed in 2517 and 2518 are strictly empirical representations of the data base used in each case.

(2) The data bases used in 2517 and 2518 were limited in range and number of variables covered.

(a) In neither case was sufficient data available on which to base a correlation on crude oil losses and hence the gasoline loss equations were used with somewhat arbitrarily chosen coefficients to correct for crude oil emissions.

(b) In neither case were diameters over 150 ft tested nor stocks less than 1.9 psia true vapor pressure.

(c) For the fixed roof tanks (2518) the data base was biased in that high vapor pressure stocks tended to apply to larger tanks and low vapor pressure stocks to small tanks. This could have led to establishing misleading coefficients for the loss equations.

(d) In all cases the tests used in establishing the data bases were conducted prior to the publishing of API Bulletin 2512 on standard test methods. Therefore, the exact methods used in conducting the tests are unknown, however, it was assumed that the tests followed generally the methods outlined in 2512.

(3) The accuracy claimed for the correlations in estimating losses is misleading. In one case (breathing losses for fixed roof tanks) the claim was made that the calculated loss would be within 10 percent of the actual loss "in most cases". The standard deviation of this equation in reproducing its own data base was 35 percent, indicating a greater error than was stated.

(4) Based on the above findings it is felt that the existing correlations are not valid when extrapolating outside the original data base (that is, to stocks less than about 2.0 psia true vapor pressure, to tanks greater than 150 feet in diameter, and to seals or tank features that were not used in developing the test data). Also, the accuracy of the correlations in predicting emissions within the data base is questionable. More accurate correlations could probably be developed without great difficulty, however, this would probably not be worthwhile in lieu of the inherent limitations of the data base.

- Analysis of Current API Test Methods for Measuring Hydrocarbon Emissions from Petroleum Storage Tanks

  (1) The test methods described in API 2512[5] are based on first principals - that is, they involve direct measurement of loss with basic instrumentation. As such, the accuracy of these tests depends mostly on the manner in which they are conducted and little chance is seen for improving on their accuracy if the procedures of API 2512 are strictly followed. The stated accuracy of the tests is ± 10 percent if the guidelines are followed. No justification was given for the selection of this degree of accuracy and a rigorous error analysis would be necessary to substantiate it.

  (2) The major drawback of the API test procedures is the amount of time necessary for significant test results. For floating roof tanks, test times of from 6 months to 1 year are recommended for accurate results using either the density change or vapor pressure change method. These long test times require removing tanks from service for extended periods (no stock additions are allowed) and make it difficult if not impossible to evaluate the effects of windage, temperature changes, barometric pressure changes, and other variables that change significantly many times during the test period. Little opportunity exists for reducing the test times required by these methods.

- Development of Short-Term Test Procedures

  (1) Of the various short-term test technique possibilities analyzed for floating roof tanks, the one that appears most attractive for development is a local enclosure over the seal space using either a steady state or concentration buildup measurement technique. There are several reasons for this conclusion.

    (a) Calculations show that by using the local enclosure technique significant test results can be obtained with test times on the order of a few hours or less for a wide range of tank sizes and emission rates.* Such short test times would allow accurate determination of effects of diurnal variables such as temperature and barometric pressure.

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* The actual time a tank would be out of service for testing depends on the extent of the test program (number of variables to be studied) and setup time required.

(b) The enclosure technique represents a direct measurement of emissions from the total seal area of the tank. Emissions measurements can be performed with standard accepted flow metering and hydrocarbon measuring instruments. These considerations are important in establishing the acceptability of emissions data that may be developed in the future.

(c) Due to the presence of the enclosure, windage effects would be eliminated. This may be an advantage because in actual field tests windage is an uncontrollable variable having an unknown effect. In nonenclosure techniques this effect would have to be correlated over a number of tests. The enclosure technique would allow simulation of windage as described in the body of the report.

(d) The principals and instruments used in the technique can also be adapted to determining emissions from other sources besides the seal, such as roof support legs, access hatches, and sampling wells.

(e) The technique can also be adapted to fixed roof tanks with internal floating covers by using the existing fixed roof as the local enclosure.

(2) Other techniques involving relatively unproven technology such as laser techniques or use of tracer gases should still be considered as they may offer more versatility, even further reduced test times, and lower test cost than the enclosure technique. However, the results of measurements made with unestablished technology would probably require comparison to those with established technology to be accepted. This further points up the need for developing a direct, short-term test procedure using established measuring methods.

RECOMMENDATIONS

As a result of information gained and analyzed on this project the following recommendations for future action are suggested for EPA consideration. These recommendations are made in lieu of the immediacy of the current petroleum storage regulatory problems in Southern California and in lieu of the fact that the Western Oil and Gas Association (WOGA), the American Petroleum Institute (API), and Chicago Bridge and Iron combined with Standard Oil of Ohio (CBI/SOHIO) are all currently planning their own emissions tests using various techniques.

(1) A program should be undertaken to develop and prove the enclosure technique described in this report on one or more small field tanks. It is suggested that WOGA be approached for possible test tanks which are already dedicated for testing. This would also allow for comparison of emission results with those of WOGA and CBI/SOHIO. The CBI/SOHIO mock-up tank is also a possibility, though less attractive than an actual field tank.

(2) Concurrent with the development of the enclosure technique, a study should be undertaken to develop a preliminary test plan for establishing a new data base and emissions estimation procedure. This study should be completed by the time the short-term test technique is developed. The purpose of this study would be to lay out a test schedule determining the numbers of tanks, tank types, and test conditions that should be evaluated. It would also outline a procedure for correlating the data gathered in field tests into a usable emissions estimating model.

(3) The results of the tests by WOGA and CBI/SOHIO should be closely scrutinized by EPA. The results of these tests will undoubtedly be compared with any future data obtained by EPA. It is important that EPA have close knowledge of the method and manner with which the tests are conducted in order to explain any differences that may occur and in order to evaluate the validity of the data. This close knowledge could be obtained by having trained observers visit the various test sites for at least some of the tests to observe the method of data acquisition and reduction.

REFERENCES

(1) "Symposium on Evaporation Loss" Proceedings, American Petroleum Institute, Vol. 32, 1952, pp 212-281.

(2) API Bulletin 2517: Evaporation Loss from Floating Roof Tanks, American Petroleum Institute, 1962.

(3) API Bulletin 2518: Evaporation Loss from Fixed-Roof Tanks, American Petroleum Institute, 1962.

(4) API Bulletin 2519: Use of Internal Floating Covers for Fixed-Roof Tanks to Reduce Evaporation Loss, American Petroleum Institute, 1962

(5) API Bulletin 2512: Tentative Methods of Measuring Evaporation Loss from Petroleum Tanks and Transportation Equipment, American Petroleum Institute, 1957.

(6) API Bulletin 928: Hydrocarton Emissions from Refineries, American Petroleum Institute, 1973.

(7) API Bulletin 2515: Use of Plastic Foam to Reduce Evaporation Loss, American Petroleum Institute, 1961.

(8) API Bulletin 2513: Evaporation Loss in the Petroleum Industry--Causes and Control, American Petroleum Institute, 1959.

(9) Boardman, H. C., "Storage of Volatile Petroleum Products", Petroleum Refiner, Vol. 25, No. 4, pp 109-116 [149-156], 1946.

(10) Bridgeman, P. W., "Dimensional Analyses", Harvard University Press, 1921.

(11) Kline, S. J., "Similitude and Approximation Theory", McGraw Hill, 1965.

APPENDIX A

LIST OF VENDORS CONTACTED FOR INFORMATION
ON TANK EMISSION CONTROL

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LIST OF VENDORS CONTACTED FOR INFORMATION ON TANK EMISSION CONTROL

Consolidated Aluminum Company
Nesquehoning, Pennsylvania
Larry Oxley 717-669-9411

Pittsburgh Des Moines Steel Co.
Neville Island
Pittsburgh, Pennsylvania
Mike McLaughlin 412-331-3000 -- internal roofs
Dean McKibben -- floating roofs

Petrex
Warren, Pennsylvania
Mr. Bloomquist 814-723-2050

Tresco
Sapulca, Oklahoma
Mark Englebrecht 918-224-9600

Mayflower
Little Ferry, New Jersey
Norm Plantz 201-641-0200

General American Transportation
Chicago, Illinois
Mr. O'Garrett 312-621-6200

Graver Tank and Manufacturing
East Chicago, Indiana
Robert Bodley 219-392-9300

Chicago Bridge and Iron Co.
Chicago, Illinois
Jim Mayer 312-654-7403

Robert Brown Associates
Carson California
Robert Brown 213-770-3630

ULTRAFLOTE Corporation
Houston, Texas
Ron Kern 713-461-2100